364	449
Class	Subclass

ISSUE CLASSIFICATION

[redacted]

5566073

UTILITY SERIAL NUMBER **08/513298**

PATENT DATE OCT 1 5 1996

PATENT NUMBER 5566073

SERIAL NUMBER	FILING DATE	CLASS	SUBCLASS	GROUP ART UNIT	EXAMINER
08/513,298	08/09/95	364	449	2304	Nguyen

APPLICANTS

JED MARGOLIN, SAN JOSE, CA.

CONTINUING DATA*******************
VERIFIED THIS APPL'N IS A CON OF 08/274,594 07/11/94 ABN
TN

FOREIGN/PCT APPLICATIONS**********
VERIFIED
TN

***** SMALL ENTITY *****

Foreign priority claimed 35 USC 119 conditions met / Verified and Acknowledged	AS FILED	STATE OR COUNTRY	SHEETS DRWGS.	TOTAL CLAIMS	INDEP. CLAIMS	FILING FEE RECEIVED	ATTORNEY'S DOCKET NO.
☐ yes ☒ no; ☐ yes ☒ no; TN Examiner's initials	→	CA	13	37	4	$590.00	02055.P002 C

ADDRESS

EDWIN H TAYLOR
BLAKELY SOKOLOFF TAYLOR & ZAFMAN
12400 WILSHIRE BLVD SEVENTH FLOOR
LOS ANGELES CA 90025

ISSUE FEE IN FILE

TITLE

PILOT AID USING A SYNTHETIC ~~REALITY~~ Environment

#6 5-9-95

U.S. DEPT. OF COMM./PAT. & TM—PTO-436L (Rev.12-94)

PARTS OF APPLICATION FILED SEPARATELY

Applications Examiner

NOTICE OF ALLOWANCE MAILED: 6-18-96

TAN NGUYEN
Assistant Examiner

CLAIMS ALLOWED

Total Claims	Print Claim
37	1

ISSUE FEE

Amount Due	Date Paid
$625.00	9-1-96

KEVIN J. TESKA
SUPERVISORY PATENT EXAMINER
GROUP 2300
Primary Examiner

DRAWING

Sheets Drwg.	Figs. Drwg.	Print Fig.
13	32	9

ISSUE BATCH NUMBER B16

Label Area

PREPARED FOR ISSUE

Form PTO-436A
(Rev. 8/92)

(FACE)

08/ CLASS | SUBCLASS | ISSUE CLASSIFICATION

[redacted]

UTILITY SERIAL NUMBER 08/274394	PATENT DATE	PATENT NUMBER

SERIAL NUMBER	FILING DATE	CLASS	SUBCLASS	GROUP ART UNIT	EXAMINER
08/274,394	07/11/94	~~375~~ 364	449	~~2614~~ 2304	NGUYEN

APPLICANTS
JED MARGOLIN, SAN JOSE, CA

CONTINUING DATA*******************
VERIFIED
TN

FOREIGN/PCT APPLICATIONS**********
VERIFIED
TN

***** SMALL ENTITY *****

Foreign priority claimed ☐ yes ☒ no 35 USC 119 conditions met ☐ yes ☒ no Verified and Acknowledged TN Examiner's Initials	AS FILED →	STATE OR COUNTRY	SHEETS DRWGS.	TOTAL CLAIMS	INDEP. CLAIMS	FILING FEE RECEIVED	ATTORNEY'S DOCKET NO.
		CA	13	13	3	$355.00	

ADDRESS
~~JED MARGOLIN~~
~~3570 PLEASANT ECHO DRIVE~~
~~SAN JOSE CA 95148-1916~~
Keith D. Askoff
Blakely, Sokoloff, Taylor & Zafman
12400 Wilshire Boulevard, 7th floor
Los Angeles CA. 90025

TITLE
PILOT AID USING A SYNTHETIC ~~REALITY~~ Environment

U.S. DEPT. of COMM.-Pat. & TM Office—PTO-436L (rev. 10-

PARTS OF APPLICATION FILED SEPARATELY	Applications Examiner

NOTICE OF ALLOWANCE MAILED	Assistant Examiner	CLAIMS ALLOWED: Total Claims / Print Claim
ISSUE FEE: Amount Due / Date Paid	Primary Examiner	DRAWING: Sheets Drwg. / Figs. Drwg. / Print Fig.
Label Area	PREPARED FOR ISSUE	ISSUE BATCH NUMBER

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(Rev. 8/92)

(FACE)

08/274394 [redacted]

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CONTENTS

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SEP 27 1994
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PAT. & T.M. OFFICE
LICENSING & REVIEW
SEP 14 1994

Date Entered or Counted	No.	Contents	Date Received or Mailed
	1.	Application ✓ papers.	
10-12-94	2.	PRIOR ART	7-11-94
11-7	3.	Rej (3)	11-9-94
	4.	Letter New Dwgs.	2-13-95
3-6	5.	Amdt. A	2-13-95
5-9	6.	Final Rej 3 Mos	5-9-95
	7.	Ex. Inter. Sum.	7-8-95
	8.	Amdt. B ne (1)	7-14-95
	9.	Chg. of Address	7-14-95
8-3	10.	Advisory Action	8-3-95
10-16 A	11.	Access Acknowledgement	10/19/95
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08/513298

PATENT APPLICATION

08513298

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INITIALS

CONTENTS

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	2.	Pre Amdt C	9-9-95
	3.	Pre Amdt D	9-9-95
	4.	~~Pre Amdt E~~ Letter	10-20-95
1-2	5.	Rejection - 3 months	1/22/96
	6.	Examiner Interview Summary Record	3-15-96
4-22	7.	Amdt E	4-19-96
6-18	8.	Notice of Allow	6-18-96
	9.	PTO Grant OCT 15 1996	
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364	449 444 448 459 460 462	11/03/94	TN
340	961 967 974 980 990 995	11/04/94	TN
342	29 450 451 463		
395	101		
update search to above		05/04/95	TN

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INTERFERENCE SEARCHED

Class	Sub.	Date	Exmr.

SEARCH NOTES

	Date	Exmr.
APS search	11/06/94	TN

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L2   (         27)SEA FILE=USPAT PLU=ON  POLYGON (10A) DATA BASE
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L4   (          0)SEA FILE=USPAT PLU=ON  L2 AND L3
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AND
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L3   (         26)SEA FILE=USPAT PLU=ON  DIGITAL (8A) DATA BASE AND POLYGON
L4   (          6)SEA FILE=USPAT PLU=ON  TERRAIN AND MANMADE (5A) STRUCTURE
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L8   (       6108)SEA FILE=USPAT PLU=ON  THREE (8A) DIMENSION### (P) (PROJEC
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L9   (      73697)SEA FILE=USPAT PLU=ON  (PAN### OR TILT### OR ZOOM OR ROUT#
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L10  (          3)SEA FILE=USPAT PLU=ON  L1 AND L2 AND L8
L11  (         46)SEA FILE=USPAT PLU=ON  L6 AND L7
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L6             12 S L3 AND ELEVATION
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340	990, 995		
345	7, 11, 23, 27		
345	119, 124, 125, 127, 129		
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INTERFERENCE SEARCHED

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364	449, 456, 457	06/14/96	TN
340	990, 995		
345	125, 127, 129		

SEARCH NOTES

	Date	Exmr.
IEEE search	12/15/95	TN

IEEE/IEE Publications Ondisc Jan 1988 - Sep 1995

Search Options:
Search for both singular and plurals: YES
Search for spelling variants : NO
Display intermediate result sets : NO

Num	Search	Hits
#1	(elevation or altitud?) and data and base	9
#2	terrain and (data or database)	573
#3	#1 and #2	3
#4	digital terrain elevation data	7
#5	#4 or dted	9

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INDEX OF CLAIMS

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SYMBOLS

- ✓ .... Rejected
- = ... Allowed
- \- (Through numeral) Canceled
- ÷ .... Restricted
- N .... Non-elected
- I .... Interference
- A .... Appeal
- O .... Objected

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SYMBOLS

- ✓ .... Rejected
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- I .... Interference
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- O .... Objected

Claim Final	Claim Original	Date	Date	Date	Date	Date	Date	Date	Date
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US005566073A

United States Patent [19]

Margolin

[11] Patent Number: 5,566,073

[45] Date of Patent: Oct. 15, 1996

2

[54] PILOT AID USING A SYNTHETIC ENVIRONMENT

[76] Inventor: Jed Margolin, 3570 Pleasant Echo Dr., San Jose, Calif. 95148-1916

[21] Appl. No.: 513,298

[22] Filed: Aug. 9, 1995

Related U.S. Application Data

[63] Continuation of Ser. No. 274,394, Jul. 11, 1994, abandoned.

[51] Int. Cl.[6] G06F 3/14; G09B 9/30

[52] U.S. Cl. 364/449; 364/456; 364/457; 340/990; 340/995; 395/127; 395/129

[58] Field of Search 364/449, 455, 364/456, 457, 460; 340/990, 995; 345/7, 11, 23, 27; 395/119, 124, 125, 127, 129

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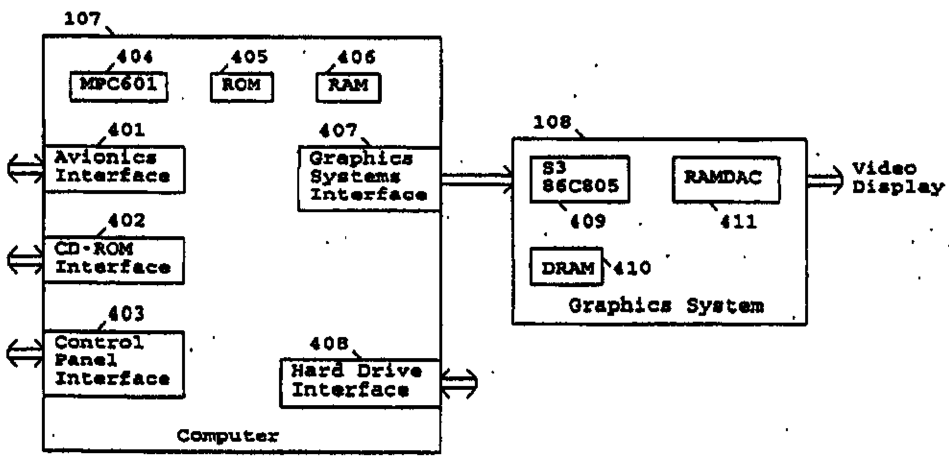
Primary Examiner—Kevin J. Teska
Assistant Examiner—Tan Nguyen
Attorney, Agent, or Firm—Blakely, Sokoloff, Taylor & Zafman

[57] ABSTRACT

A pilot aid using synthetic reality consists of a way to determine the aircraft's position and attitude such as by the global positioning system (GPS), a digital data base containing three-dimensional polygon data for terrain and manmade structures, a computer, and a display. The computer uses the aircraft's position and attitude to look up the terrain and manmade structure data in the data base and by using standard computer graphics methods creates a projected three-dimensional scene on a cockpit display. This presents the pilot with a synthesized view of the world regardless of the actual visibility. A second embodiment uses a head-mounted display with a head position sensor to provide the pilot with a synthesized view of the world that responds to where he or she is looking and which is not blocked by the cockpit or other aircraft structures. A third embodiment allows the pilot to preview the route ahead or to replay previous flights.

37 Claims, 13 Drawing Sheets



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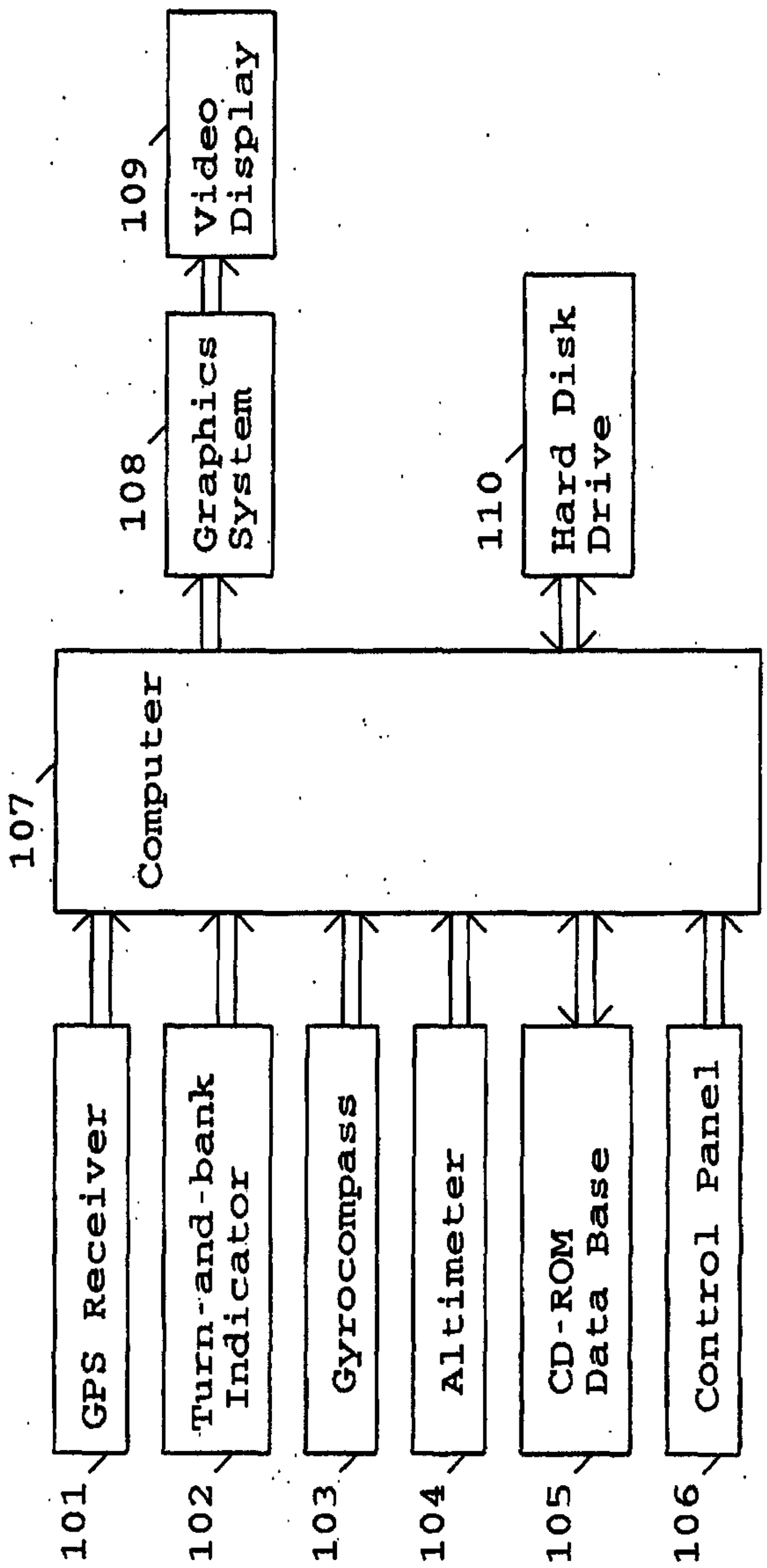

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102
Turn-and-bank Indicator
103
Gyrocompass
104
Altimeter
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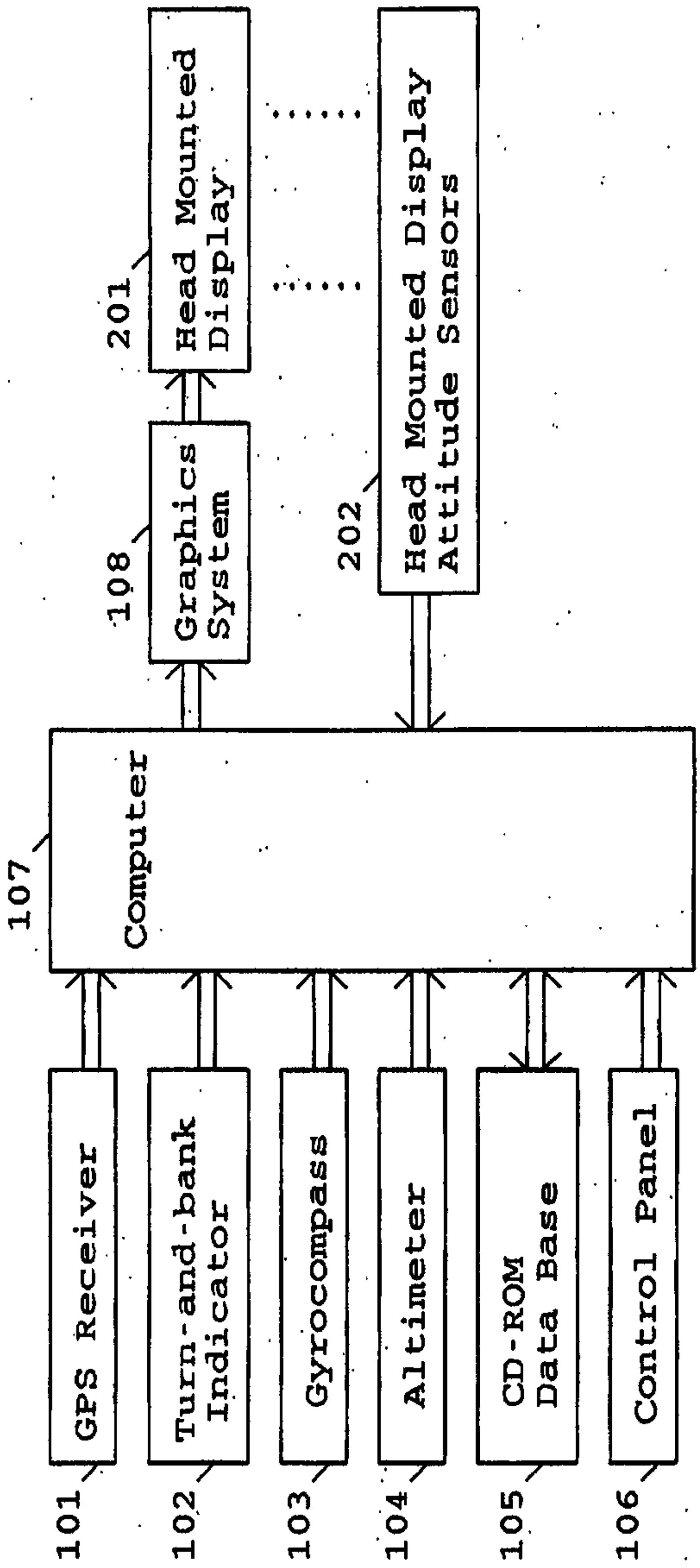
CD-ROM Data Base
106
Control Panel
107
Computer
108
Graphics System
109
Video Display
110
Hard Disk Drive

Fig. 1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CD-ROM Data Base
105
Control Panel
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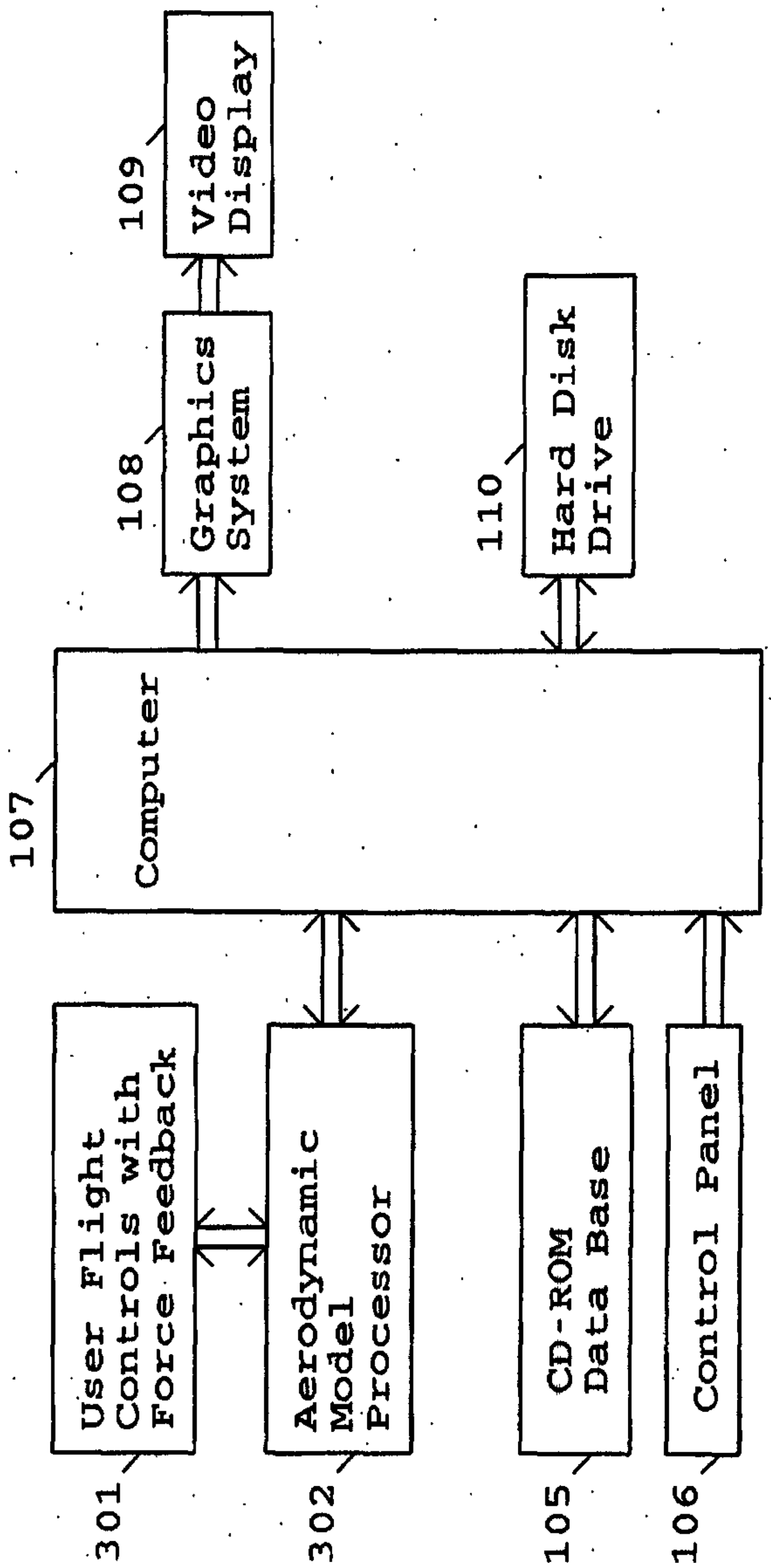
Fig. 2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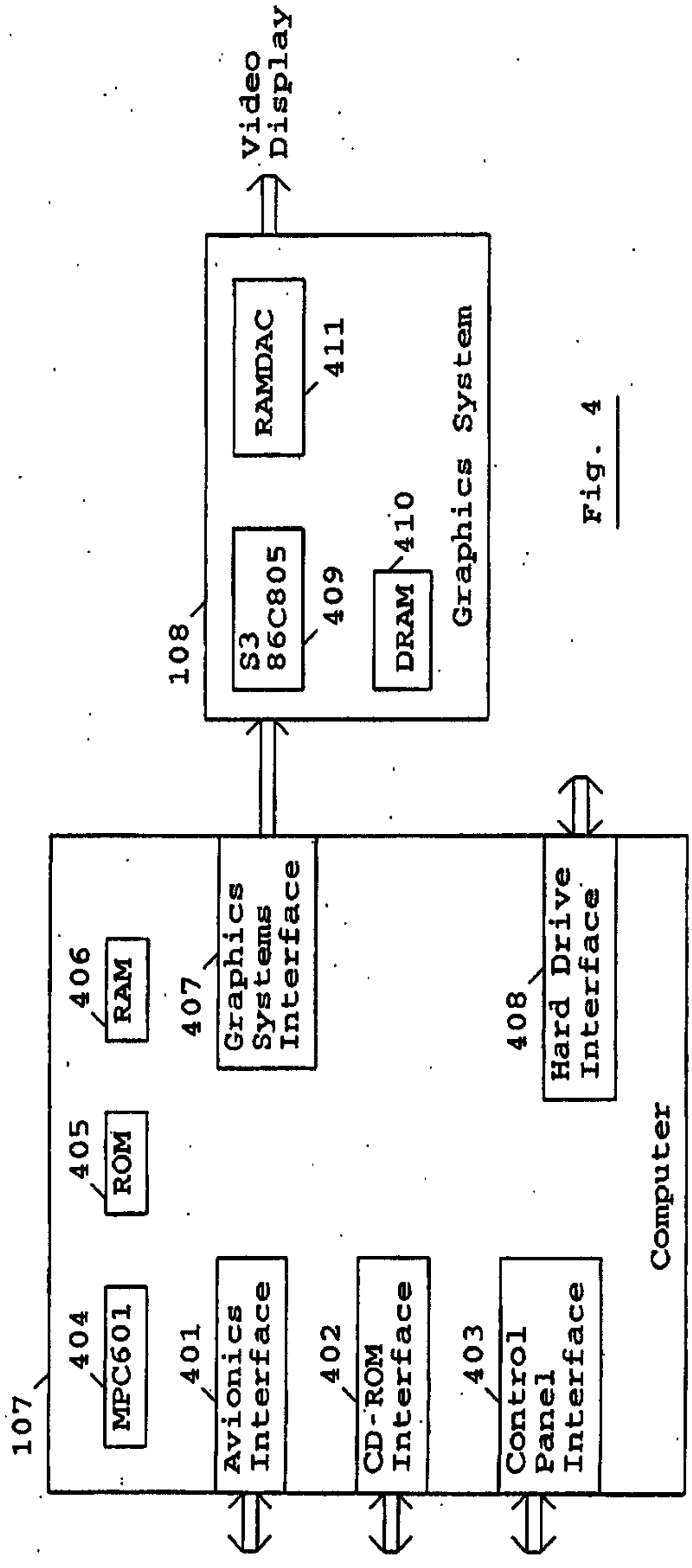
Control Panel

Fig. 3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Control Panel Interface
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Graphics Systems Interface
407
Hard Drive Interface
408
Computer

Fig. 4

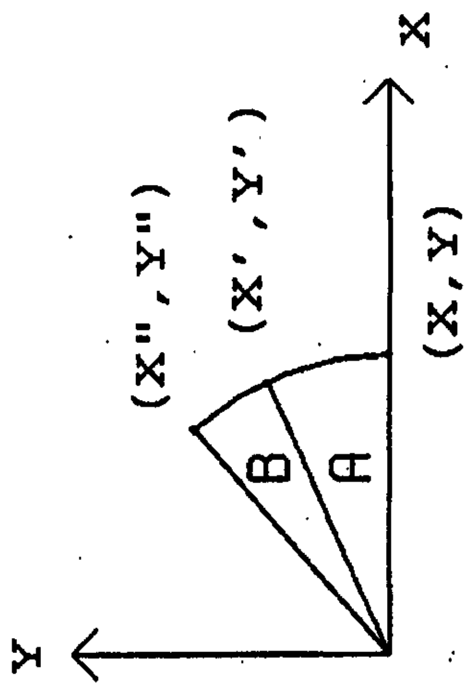
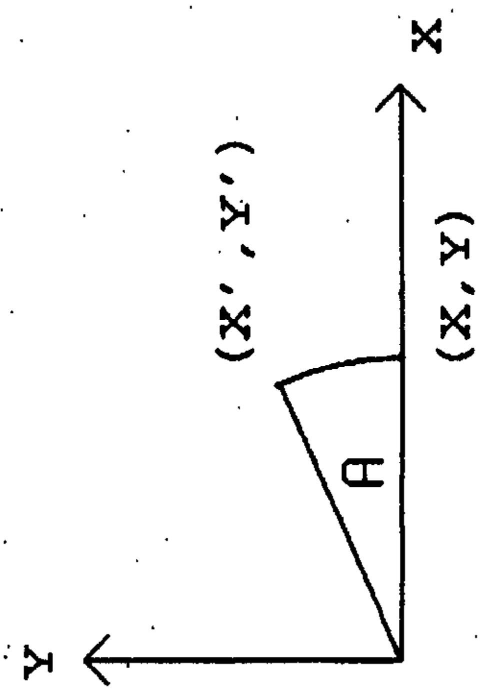


Fig. 5b



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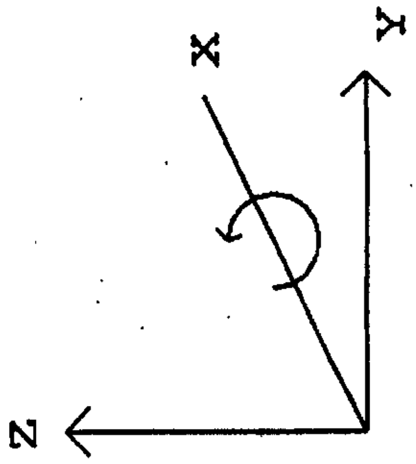

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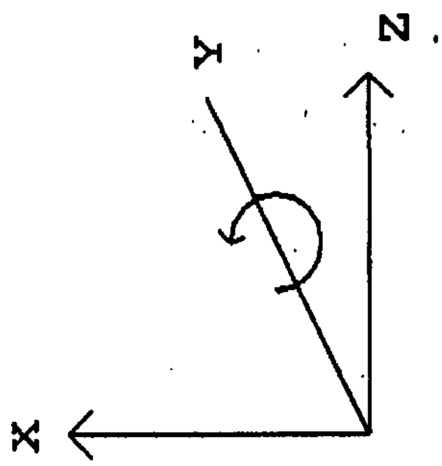

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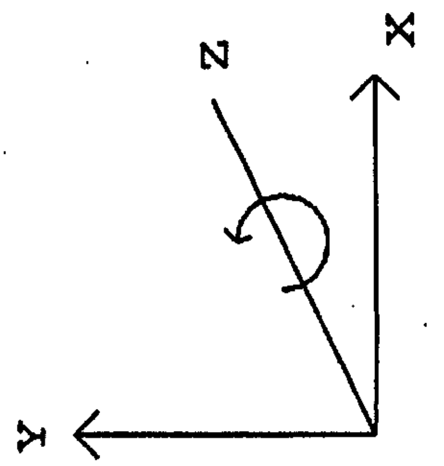

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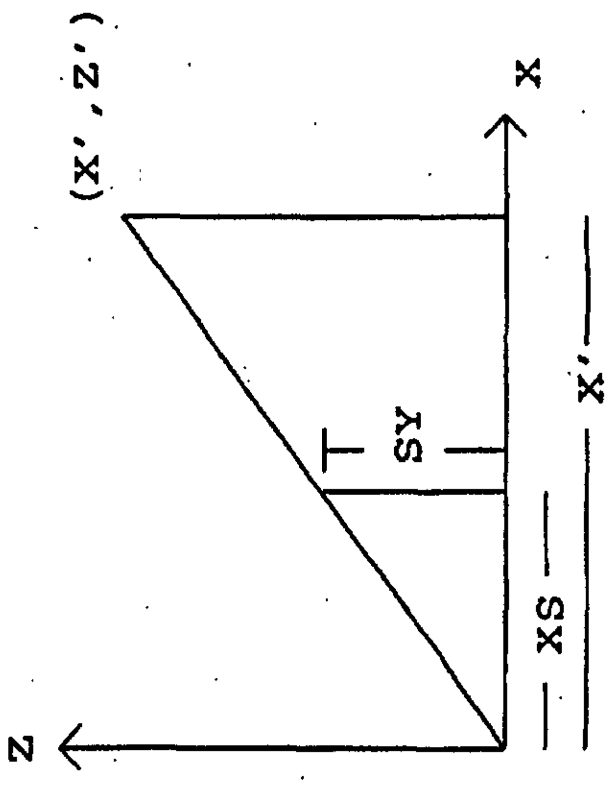

Fig. 7a Side

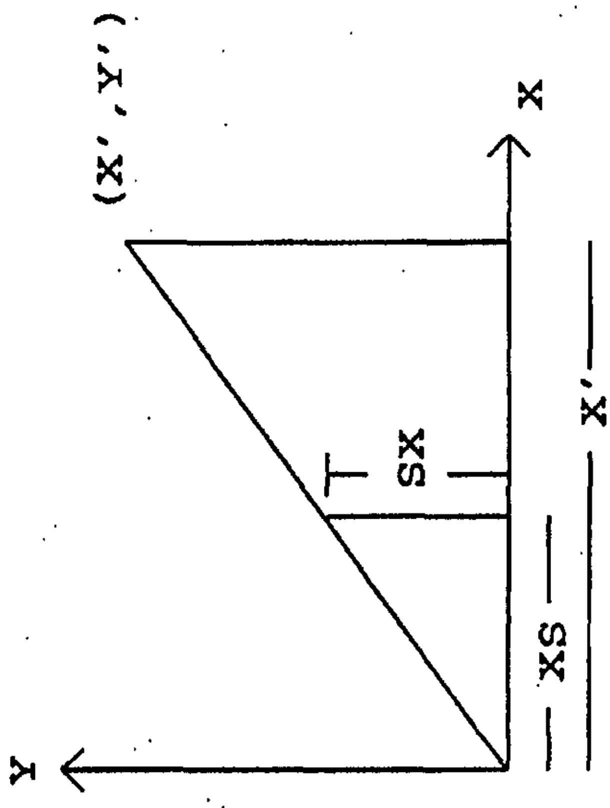

Fig. 7b Top

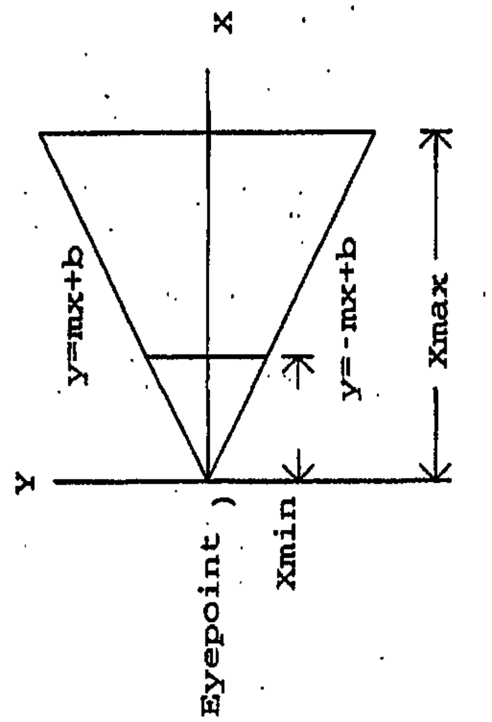

Fig. 8b Top View

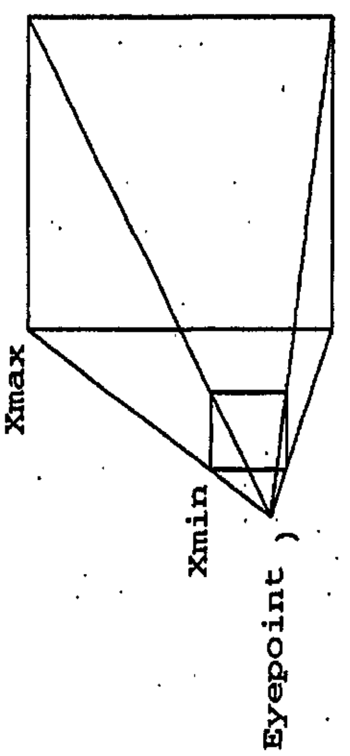

Fig. 8a

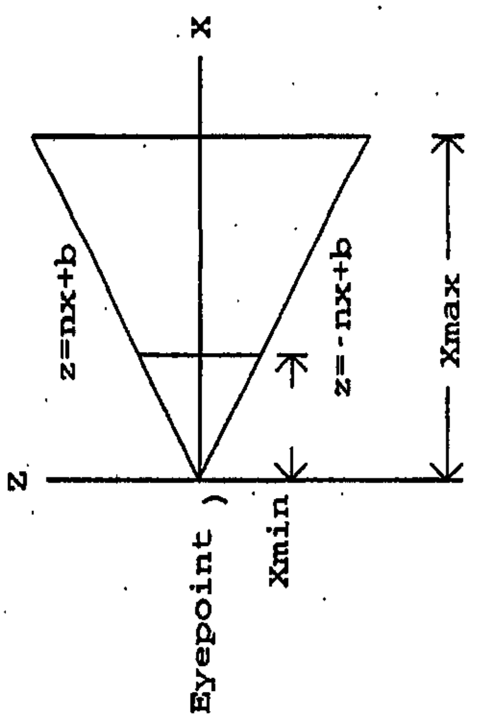

Fig. 8c Side View

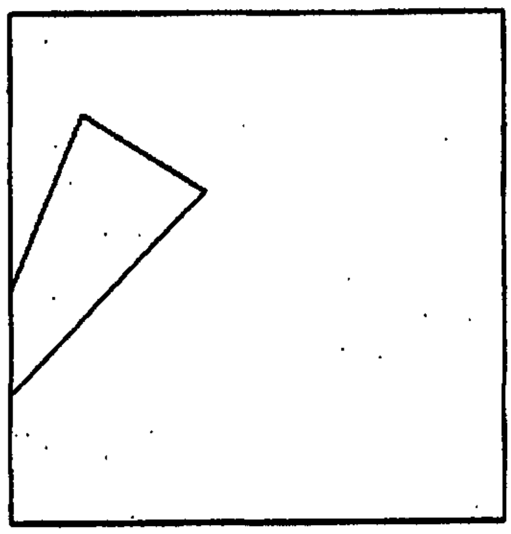

Fig. 9b

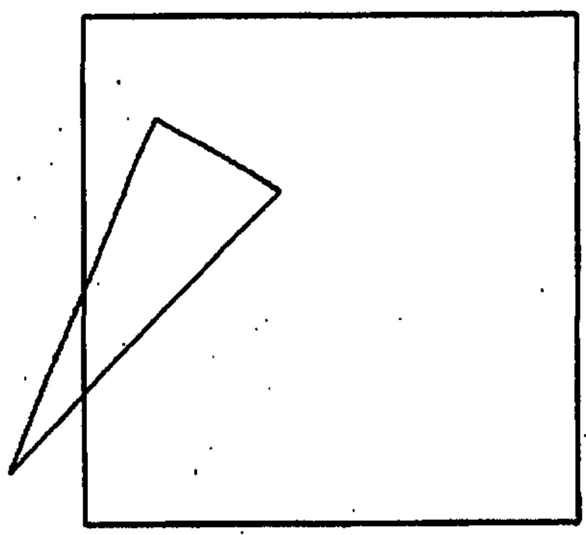

Fig. 9a

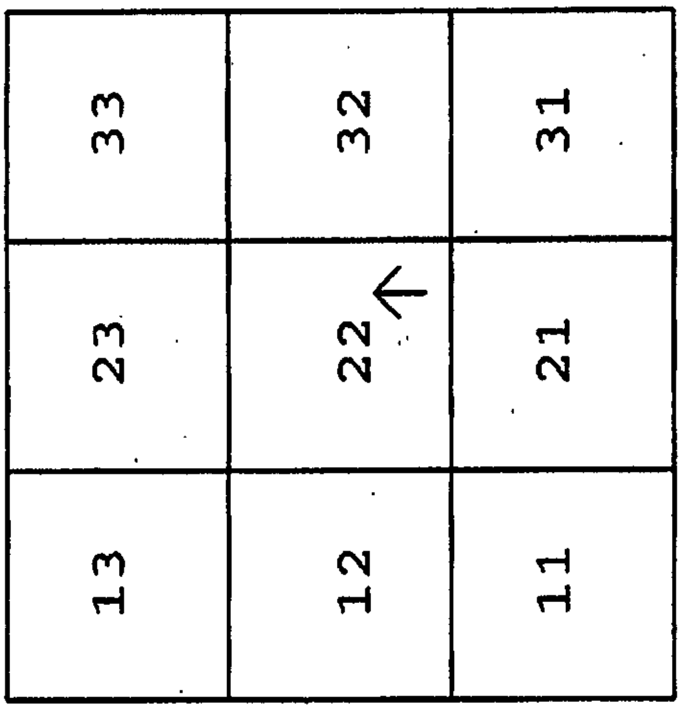

Fig. 10b

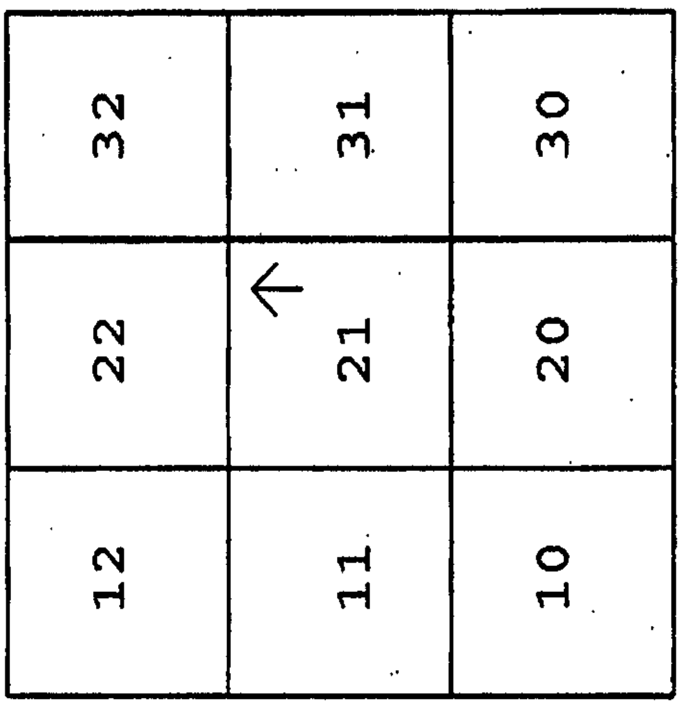

Fig. 10a

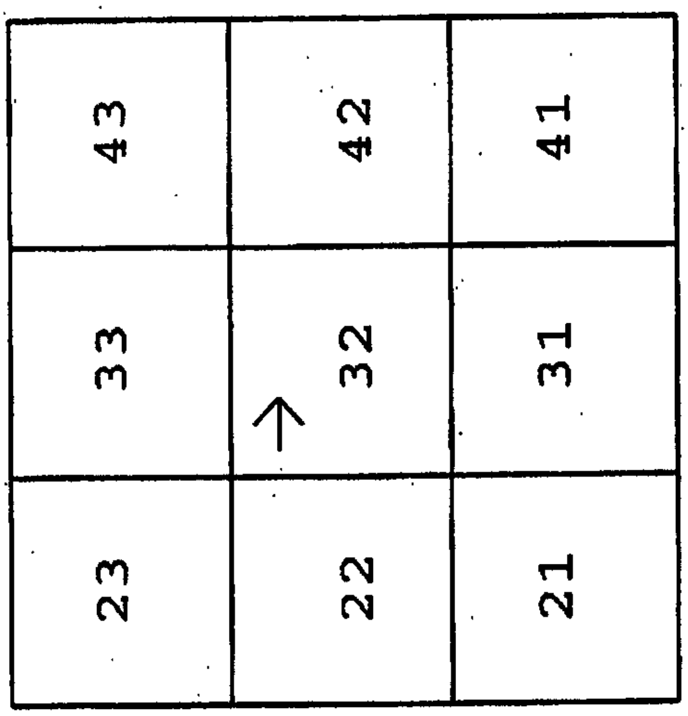

Fig. 11b

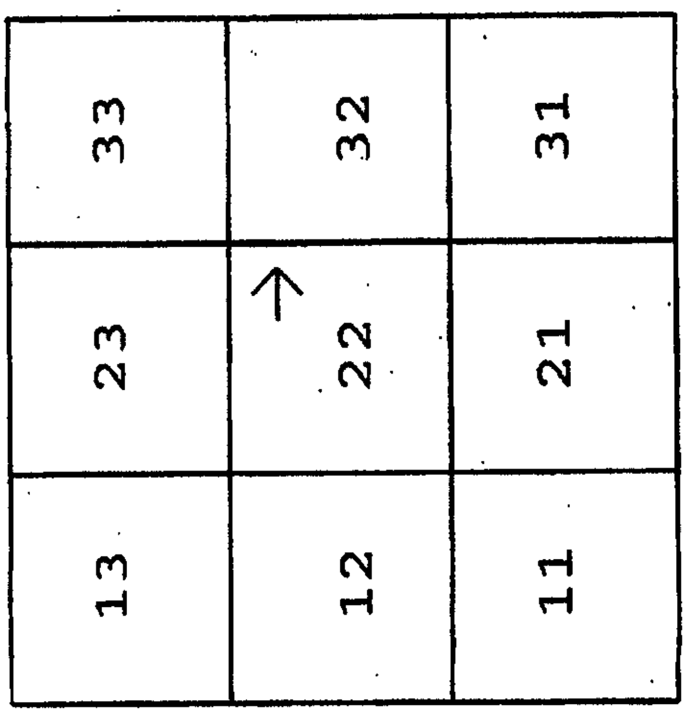

Fig. 11a

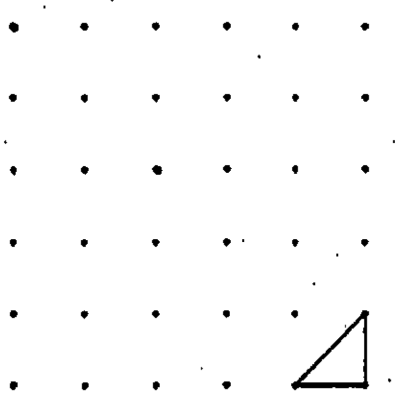

Fig. 12a

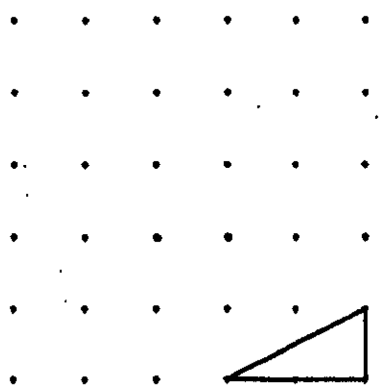

Fig. 12b

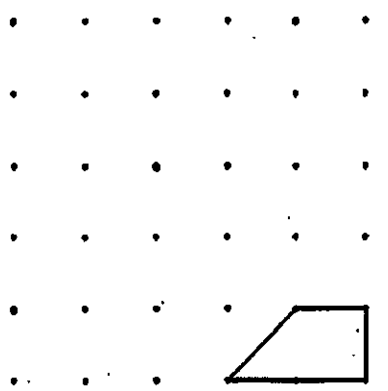

Fig. 12c

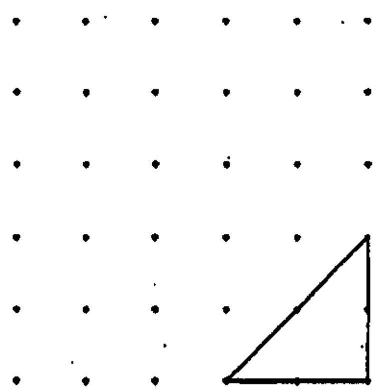

Fig. 12d

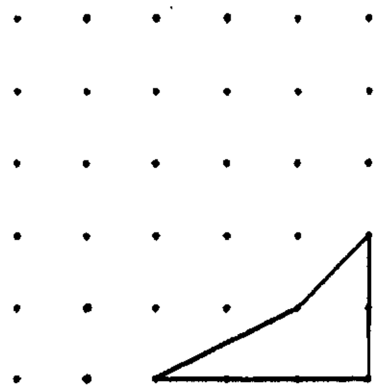

Fig. 12e

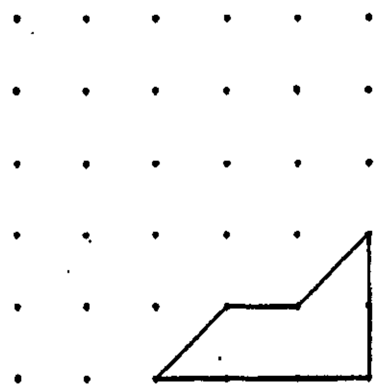

Fig. 12f

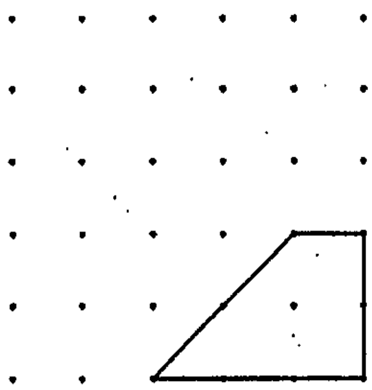

Fig. 13a

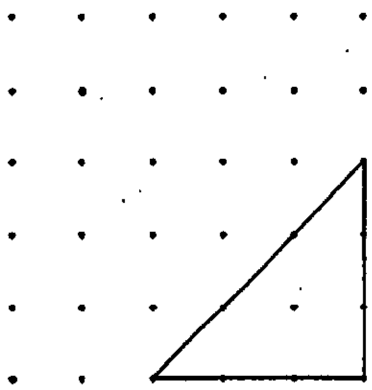

Fig. 13b

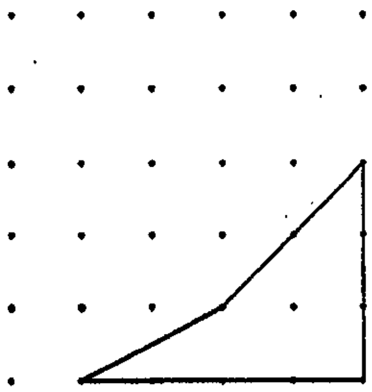

Fig. 13c

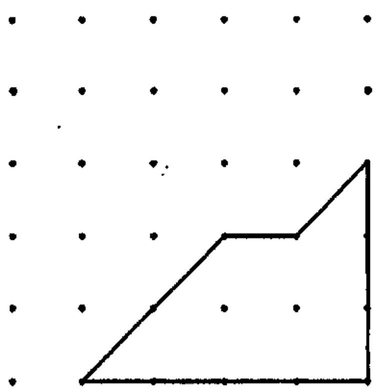

Fig. 13d

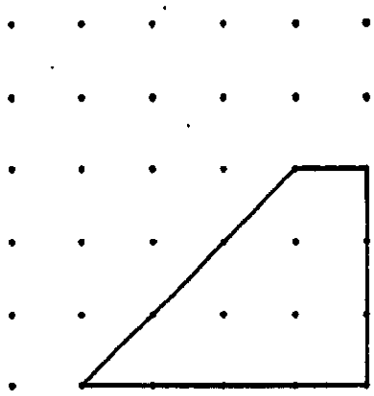

Fig. 13e

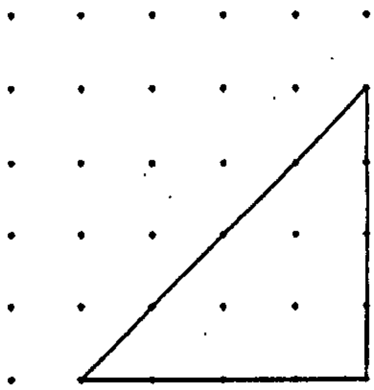

Fig. 13f

PILOT AID USING A SYNTHETIC ENVIRONMENT

This is a continuation of application Ser. No. 08/274,394, filed Jul. 11, 1994, now abandoned.

BACKGROUND OF THE INVENTION

This invention relates to a pilot aid for synthesizing a view of the world. When flying under Visual Flight Rules (VFR) the normal procedure for determining your position is to relate what you see out the window to the information on a paper map. During the day it can be difficult to determine your location because the desired landmark can be lost in the clutter of everything else. When flying at night you see mostly lights. When flying under Instrument Flight Rules (IFR) you must relate the information from various navigation aids to the information on a printed map. You must then interpret the map information in order to avoid flying into objects such as mountains and the like. An improvement in this situation came about when the global positioning system (GPS) became operational and available for civilian use. GPS directly provides map coordinates but you must still, however, interpret the map information. Systems have been developed which use GPS coordinates to access an electronic map which is presented on a display as a flat map. Systems have also been developed that present an apparent three-dimensional effect and some that present a mathematically correct texture-mapped three-dimensional projected display.

Both of these systems require a very large amount of storage for terrain data. The latter system also requires specialized hardware. Their high cost have prevented their widespread adoption by the avaiation community.

The 1984 patent to Taylor et al. (U.S. Pat. No. 4,445,118) shows the basic operation of the global positioning system (GPS).

The 1984 patent to Johnson et al. (U.S. Pat. No. 4,468,793) shows a receiver for receiving GPS signals.

The 1984 patent to Maher (U.S. Pat. No. 4,485,383) shows another receiver for receiving GPS signals.

The 1986 patent to Evans (U.S. Pat. No. 4,599,620) shows a method for determining the orientation of a moving object and producing roll, pitch, and yaw information.

The 1992 patent to Timothy et al. (U.S. Pat. No. 5,101,356) also shows a method for determining the orientation of a moving object and producing roll, pitch, and yaw information.

The 1993 patent to Ward et al. (U.S. Pat. No. 5,185,610) shows a method for determining the orientation of a moving object from a single GPS receiver and producing roll, pitch, and yaw information.

The 1992 patent to Fraughton et al. (U.S. Pat. No. 5,153,836) shows a navigation, surveillance, emergency location, and collision avoidance system and method whereby each craft determines its own position using LORAN or GPS and transmits it on a radio channel along with the craft's identification information. Each craft also receives the radio channel and thereby can determine the position and identification of other craft in the vicinity.

The 1992 patent to Beckwith et al. (U.S. Pat. No. 5,140,532) provides a topographical two-dimensional real-time display of the terrain over which the aircraft is passing, and a slope-shading technique incorporated into the system provides to the display an apparent three-dimensional effect similar to that provided by a relief map. This is accomplished by reading compressed terrain data from a cassette tape in a controlled manner based on the instantaneous geographical location of the aircraft as provided by the aircraft navigational computer system, reconstructing the compressed data by suitable processing and writing the reconstructed data into a scene memory with a north-up orientation. A read control circuit then controls the read-out of data from the scene memory with a heading-up orientation to provide a real-time display of the terrain over which the aircraft is passing. A symbol at the center of display position depicts the location of the aircraft with respect to the terrain, permitting the pilot to navigate the aircraft even under conditions of poor visibility. However, the display provided by this system is in the form of a moving map rather than a true perspective display of the terrain as it would appear to the pilot through the window of the aircraft.

The 1987 patent to Beckwith et al. (U.S. Pat. No. 4,660,157) is similar to U.S. Pat. No. 5,140,532. It also reads compressed terrain data from a cassette tape in a controlled manner based on the instantaneous geographical location of the aircraft as provided by the aircraft navigational computer system and reconstructs the compressed data by suitable processing and writing the reconstructed data into a scene memory. However, instead of providing a topographical two-dimensional display of the terrain over which the aircraft is passing and using a slope-shading technique to provide an apparent three-dimensional effect similar to that provided by a relief map as shown in the '532 patent, the '157 patent processes the data to provide a 3D perspective on the display. There are a number of differences between the '157 patent and the present invention:

1. The '157 Patent stores the map as a collection of terrain points with associated altitudes; the large amount of storage required by this approach requires that a tape be prepared for each mission. The present invention stores terrain data as a collection of polygons which results in a significant reduction of data base storage; larger geographic areas can be stored so that it it not necessary to generate a data base for each mission.
2. The '157 Patent uses a tape cassette for data base storage; the long access time for tape storage makes it necessary to use a relatively large cache memory. The present invention uses a CD-ROM which permits random access to the data so that the requirements for cache storage are reduced.
3. The '157 Patent accounts for the aircraft's heading by controlling the way the data is read out from the tape. Different heading angles result in the data being read from a different sequence of addresses. Since addresses exist only at discrete locations, the truncation of address locations causes an unavoidable change in the map shapes as the aircraft changes heading. The present invention stores terrain as polygons which are mathematically rotated as the aircraft changes attitude. The resolution is determined by number of bits used to represent the vertices of the polygons, not the number of storage addresses.
4. The '157 accounts for the roll attitude of the aircraft by mathematically rotating the screen data after it is projected. The '157 Patent does not show the display being responsive to the pitch angle of the aircraft. In systems such as this the lack of fidelity is apparent to the user. People know what things are supposed to look like and how they are supposed to change perspective when they move. The present invention uses techniques that

have long been used by the computer graphics industry to perform the mathematically correct transformation and projection.

5. The '157 shows only a single cockpit display while one of the embodiments of the present invention shows a stereographic head-mounted display with a head sensor. The pilot is presented with a synthesized view of the world that is responsive to wherever the pilot looks; the view is not blocked by the cockpit or other aircraft structures. This embodiment is not anticipated by the '157 patent.

The 1991 patent to Behensky et al. (U.S. Pat. No. 5,005,148) shows a driving simulator for a video game. The road and other terrain are produced by mathematically transforming a three-dimensional polygon data base.

The first sales brochure from Atari Games Corp. is for a coin-operated game (Hard Drivin') produced in 1989 and relates to the '148 patent. The terrain is represented by polygons in a three-dimensional space. Each polygon is transformed mathematically according to the position and orientation of the player. After being tested to determine whether it is visible and having the appropriate illumination function performed, it is clipped and projected onto the display screen. These operations are in general use by the computer graphics industry and are well known to those possessing ordinary skill in the art.

The second sales brochure from Atari Games Corp. is for a coin-operated game (Steel Talons) produced in 1991 and which also relates to the '148 patent and the use of polygons to represent terrain and other objects.

The 1993 patent to Dawson et al. (U.S. Pat. No. 5,179,638) shows a a method and apparatus for providing a texture mapped perspective view for digital map systems which includes a geometry engine that receives the elevation posts scanned from the cache memory by the shape address generator. A tiling engine is then used to transform the elevation posts into three-dimensional polygons. There are a number of differences between the '638 patent and the present invention:

1. The '638 Patent is for a digital map system only. The matter of how the location and attitude are selected is not addressed. The present invention uses a digital map as part of a system for presenting an aircraft pilot with a synthesized view of the world regardless of the actual visibility.
2. The '638 Patent stores the map as a collection of terrain points with associated altitudes, thereby requiring a large amount of data storage. The terrain points are transformed into polygons during program run-time thereby adding to the processing burden. The present invention stores terrain data as a collection of polygons which results in a significant reduction of data base storage.
3. The present invention also teaches the use of a stereographic head-mounted display with a head sensor. The pilot is presented with a synthesized view of the world that is responsive to wherever the pilot looks; the view is not blocked by the cockpit or other aircraft structures. This embodiment is not anticipated by the '638 patent.

The 1994 patent to Hamilton et al. (U.S. Pat. No. 5,296,854) shows a helicopter virtual display system in which the structual outlines corresponding to structual members forming the canopy structure are added to the head-up display in order to replace the canopy structure clues used by pilots which would otherwise be lost by the use of the head-up display.

The 1994 patent to Lewins (U.S. Pat. No. 5,302,964) shows a head-up display for an aircraft and incorporates a cathode-ray tube image generator with a digital look-up table for distortion correction. An optical system projects an image formed on the CRT screen onto a holographic mirror combiner which is transparent to the pilot's direct view through the aircraft windshield.

The sales brochure from the Polhemus company shows the commercial availability of a position and orientation sensor which can be used on a head-mounted display.

The article from EDN magazine, Jan. 7, 1993, pages 31–42, entitled "System revolutionizes surveying and navigation" is an overview of how the global positioning system (GPS) works and lists several manufacturers of commercially available receivers. The article also mentions several applications such as the use by geologists to monitor fault lines, by oil companies for off-shore oil explorations, for keeping track of lower-orbit satellites, by fleet vehicle operators to keep track of their fleet, for crop sprayers to spread fertilizer and pesticides more efficiently, and for in-car systems to display maps for automotive navigation.

The section from "Aviator's Guide to GPS" presents a history of the GPS program.

The sales brochure from Megellan Systems Corp. is for commercially available equipment comprising a GPS receiver with a moving map display. The map that is displayed is a flat map.

The sales brochure from Trimble Navigation is for a commercially available GPS receiver.

The sales brochure from the U.S. Geological survey shows the availability of Digital Elevation Models for all of the United States and its territories.

The second sales brochure from the U.S. Geological survey shows the availability of Digital Line Graph Models for all of the United States and its territories. The data includes: political and administrative boundaries; hydrography consisting of all flowing water, standing water, and wetlands; major transportation systems consisting of roads and trails, railroads, pipelines, transmission lines, and airports; and significant manmade structures.

The Washington Sectional Aeronautical Chart is a paper map published by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration that shows the complexity of the information that an aircraft pilot needs in order to fly in the area covered by the map. The other areas of the U.S. are covered by similar maps.

The sales brochure from Jeppesen Sanderson shows that the company makes its navigation data base available in computer readable form.

Accordingly, several objects and advantages of my invention are to provide a system that produces a mathematically correct three-dimensional projected view of the terrain while reducing the amount of storage required for the data base and which can be accomplished by using standard commercially available components. The invention can be used as a real-time inflight aid or it can be used to preview a flight, or it can be used to replay and review a previous flight.

Further objects and advantages of my invention will become apparent from a consideration of the drawings and ensuing description.

SUMMARY OF THE INVENTION

The present invention is a pilot aid which uses the aircraft's position and attitude to transform data from a digital data base to present a pilot with a synthesized three-dimensional projected view of the world. The three-dimensional position is typically determined by using the output of a commercially available GPS receiver. As a safety check, the altitude calculated by the GPS receiver can be compared to the output of either a standard altimeter or a radio altimeter. Attitude can also be determined from the use of a GPS receiver or it can be derived from standard avionic instruments such as turn-and-bank indicator and gyrocompass. The digital data base represents the terrain and manmade structures as collections of polygons in order to minimize storage requirements. The pilot can select several feature such as pan, tilt, and zoom which would allow the pilot to see a synthesized view of terrain that would otherwise be blocked by the aircraft's structure, especially on a low-wing aircraft. The pilot can also preview the route either inflight or on the ground. Because the system has the ability to save the flying parameters from a flight, the pilot can replay all or part of a previous flight, and can even take over during the replay to try out different flight strategies. Through the use of a head-mounted display with a head sensor, the pilot can have complete range of motion to receive a synthesized view of the world, completely unhindered by the aircraft structure.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram showing the output to a single video display.

FIG. 2 is a block diagram showing the output to a head-mounted display.

FIG. 3 is a block diagram showing a system used to plan and/or replay a particular flight.

FIG. 4 is a block diagram showing Computer 107 and Graphics System 108 in FIG. 1, FIG. 2, and FIG. 3.

FIG. 5*a* shows a simple positive (counter-clockwise) rotation of a point around the origin of a 2-Dimensional space.

FIG. 5*b* shows a second positive (counter-clockwise) rotation of a point around the origin of a 2-Dimensional space.

FIG. 6*a* shows the equivalent three dimensional space of FIG. 5*a* where the rotation is around the Z axis.

FIG. 6*b* is a re-orientation of the axes of FIG. 6*a* showing rotation around the Y axis.

FIG. 6*c* is a re-orientation of the axes of FIG. 6*a* showing rotation around the X axis.

FIG. 7*a* is a side view showing the projection of a point in three-dimensions projected onto a two-dimensional screen.

FIG. 7*b* is a top view showing the projection of a point in three-dimensions projected onto a two-dimensional screen.

FIG. 8*a* is a cabinet-projected three-dimensional representation of the viewing pyramid.

FIG. 8*b* is a 2D top view of the viewing pyramid.

FIG. 8*c* is a 2D side view of the viewing pyramid.

FIG. 9*a* shows an unclipped polygon.

FIG. 9*b* shows how clipping the polygon in FIG. 9*a* produces additional sides to the polygon.

FIG. 10*a* shows the impending crossover from Geographic Data Block 21 to Geographic Data Block 22.

FIG. 10*b* shows the result of a crossover from Geographic Data Block 21 to Geographic Data Block 22.

FIG. 11*a* shows the impending crossover from Geographic Data Block 22 to Geographic Data Block 32.

FIG. 11*b* shows the result of a crossover from Geographic Data Block 22 to Geographic Data Block 32.

FIG. 12*a* through FIG. 12*f*, and FIG. 13*a* through FIG. 13*f* show the procedure for generating the polygon data base from the Digital Elevation Model data.

DETAILED SPECIFICATION

FIG. 1 shows the basic form of the invention. GPS Receiver 101 receives signals from the satellites that make up the global positioning system (GPS) and calculates the aircraft's position in three dimensions. Altimeter 104 provides an output of the aircraft's altitude as a safety check in the event GPS Receiver 101 malfunctions. Turn-and-bank Indicator 102 and Gyrocompass 103 provide the aircraft's attitude which comprises heading, roll, and pitch. CD-ROM Data Base 105 contains the digital data base consisting of three-dimensional polygon data for terrain and manmade structures.

Computer 107 is shown in more detail in FIG. 4 and uses commercially available integrated circuits including processor 404, the MPC601, from Motorola Semiconductor Inc. The MPC601 is a fast 32-bit RISC processor with a floating point unit and a 32K Byte eight-way set-associative unified instruction and data cache. Most integer instructions are executed in one clock cycle. Compilers are available for ANSI standard C and for ANSI standard FORTRAN 77. Computer 107 also contains ROM 405, RAM 406, Avionics Interface 401, CD-ROM Interface 402, Control Panel Interface 403, Graphics Systems Interface 407, and Hard Drive Interface 408.

Computer 107 uses the aircraft's position from GPS Receiver 101 to look up the terrain and manmade structure data in CD-ROM Data Base 105. This data is organized in geographic blocks and is accessed so that there is always the proper data present. This is shown in FIG. 10*a*. FIG. 10*b* shows that when the aircraft crosses from Block 21 to Block 22, the data from Blocks 10, 20, and 30 are discarded and data from Blocks 13, 23, and 33 are brought in from CD-ROM Data Base 105. FIG. 11*a* and FIG. 11*b* show the aircraft crossing from Block 22 to Block 32.

Computer 107 uses the aircraft's position from GPS Receiver 101 and attitude information from Turn-and-bank Indicator 102 and Gyrocompass 103 to mathematically operate on the terrain and manmade structure data to present three-dimensional projected polygons to Graphics System 108. As shown in FIG. 4, Graphics System 108 consists of a commercially available graphics integrated circuit 409, the 86C805, made by S3 Incorporated. This integrated circuit contains primitives for drawing lines in addition to the standard SVGA graphics functions. The 86C805 controls DRAM 410 which is the video memory consisting of two buffers of 1024×768 pixels, each of which is 8 bits deep. The video to be displayed from DRAM 410 is sent to RAMDAC 411 which is an integrated circuit commercially available from several manufacturers, such as Brooktree and AT&T. RAMDAC 411 contains a small RAM of 256×24 bits and three 8-bit DACs. The RAM section is a color table programmed to assign the desired color to each of the 256 combinations possible by having 8 bits/pixel and is combined with three video DACs, one for each color for Video Display 109.

Video Display 109 is a color video display of conventional design such as a standard CRT, an LCD panel, or a plasma display panel. The preferred size of Video Display 109 is 19" although other sizes may be used.

FIG. 2 shows the use of the system with Head Mounted Display 201. Head Mounted Display Attitude Sensors 202 provide Computer 107 with the orientation of Head Mounted Display 201. This orientation is concatenated with the aircraft's orientation provided by Turn-and-bank Indicator 102 and Gyrocompass 103. As a consequence the pilot can turn his or her head and view the three-dimensional synthesized view of the transformed terrain and manmade structure data unhindered by the aircraft's structure. With the appropriate sensors for engines, fuel tanks, doors, and the like, the pilot can be presented with synthesized representations of these objects in their correct locations. For example, the pilot would be able to 'look' at a fuel tank and 'see' if it is running low. The pilot would also be able to 'see' if there is a problem with an engine and, on multi-engine aircraft, identify which one. By using a technique similar to that taught in the 1992 patent to Fraughton et al. (U.S. Pat. No. 5,153,836) where each aircraft determines its own position using LORAN or GPS and transmits it on a radio channel along with the aircraft's identification information so that each craft also receives the radio channel and can thereby determine the position and identification of other craft in the vicinity, these other aircraft can be presented in the present invention as three-dimensional objects in their correct positions to alert the pilot to their presence and take evasive maneuvers as required.

Hard Disk Drive 110 is for recording the aircraft's position and orientation data for later playback in order to review the flight. Because the information presented on Video Display 109 is a function of the aircraft's position and orientation data applied to the CD-ROM Data Base 105, it can be reconstructed later at any time by storing just the aircraft's position and orientation data and applying it again to CD-ROM Data Base 106, as long as the data base is still available. The aircraft's position and orientation data requires fewer than 100 bytes. By recording it every 0.1 seconds, an hour requires about 3.6 Megabytes of storage. (100 bytes/update×10 updates/second×60 seconds/min×60 minutes/hour=about 3.6 Megabytes) Therefore, a standard 340 Megabyte hard drive would store about 94 hours of operation.

A method for previewing a route that has not been flown before is shown in FIG. 3. GPS Receiver 101, Turn-and-bank Indicator 102, Gyrocompass 103, and Altimeter 104 are replaced by User Flight Controls with Force Feedback 301 and Aerodynamic Model Processor 302. Aerodynamic Model Processor 302 is a processor that implements the aerodynamic mathematical model for the type of aircraft desired. It receives the user inputs from User Flight Control with Force Feedback 301, performs the mathematical calculations to simulate the desired aircraft, and supplies output back to the Force Feedback part of the controls and to Computer 107. The outputs supplied to Computer 107 simulate the outputs normally supplied to GPS Receiver 101, Turn-and-bank Indicator 102, Gyrocompass 103, and Altimeter 104. In this way, Computer 107 executes exactly the same program that it would perform in the in-flight system. This permits the pilot to practice flying routes that he or she has not flown before and is particularly useful in practicing approach and landing at unfamiliar airports. This system does not need to be installed in an aircraft; it can be installed in any convenient location, even the pilot's home.

Control Panel 106 allows the pilot to select different operating features. For example, the pilot can choose the 'look angle' of the display (pan and tilt). This would allow the pilot to see synthesized terrain corresponding to real terrain that would otherwise be blocked by the aircraft's structure like the nose, or the wing on a low wing aircraft. Another feature is the zoom function which provides magnification. Another feature is to permit the pilot to select a section of the route other than the one he or she is on, for example, to preview the approach to the destination airport.

MATH INTRO

The math for the present invention has been used in the field of coin-operated video games and in traditional computer graphics. However, since it has not been well documented, it will be presented here. The basic concept assumes the unit is a simulator, responsive to the user's inputs. It is a short step from that to the present invention where the inputs represent the physical location and attitude of the aircraft.

The steps required to view a 3D polygon-based data base are:

1. Transformation (translation and rotation as required)
2. Visibility and illumination
3. Clipping
4. Projection

In this geometric model there is an absolute Universe filled with Objects, each of which is free to rotate and translate. Associated with each Object is an Orthonormal Matrix (i.e. a set of Orthogonal Unit Vectors) that decribes the Object's orientation with respect to the Universe. Because the Unit Vectors are Orthogonal, the Inverse of the matrix is simply the Transpose. This makes it very easy to change the point of reference. The Object may look at the Universe or the Universe may look at the Object. The Object may look at another Object after the appropriate concatenation of Unit Vectors. Each Object will always Roll, Pitch, or Yaw around its own axes regardless of its current orientation without using Euler angle functions.

ROTATIONS

The convention used here is that the Z axis is straight up, the X axis is straight ahead, and the Y axis is to the right. ROLL is a rotation around the X axis, PITCH is a rotation around the Y axis, and YAW is a rotation around the Z axis.

For a simple positive (counter-clockwise) rotation of a point around the origin of a 2-Dimensional space:

$$X'=X*COS(a)-Y*SIN(a)$$

$$Y'=X*SIN(a)+Y*COS(a)$$

See FIG. 5*a*.

If we want to rotate the point again there are two choices:

1. Simply sum the angles and rotate the original points, in which case:

$$X''=X*COS(a+b)-Y*SIN(a+b)$$

$$Y''=X*SIN(a+b)+Y*COS(a+b)$$

2. Rotate X', Y' by angle b:

$$X''=X'*COS(b)-Y'*SIN(b)$$

$$Y''=X'*SIN(b)+Y'*COS(b)$$

See FIG. 5*b*.

With the second method the errors are cumulative. The first method preserves the accuracy of the original coordinates; unfortunately it works only for rotations around a single axis. When a series of rotations are done together around two or three axes, the order of rotation makes a difference. As an example: An airplane always Rolls, Pitches, and Yaws according to its own axes. Visualize an airplane suspended in air, wings straight and level, nose pointed North. Roll 90 degrees clockwise, then pitch 90 degrees "up". The nose will be pointing East. Now we will start over and reverse the order of rotation. Start from straight and level, pointing North. Pitch up 90 degrees, then Roll 90 degrees clockwise, The nose will now be pointing straight up, where "up" is referenced to the ground. If you have trouble visualizing these motions, Just pretend your hand is the airplane.

This means that we cannot simply keep a running sum of the angles for each axis. The standard method is to use functions of Euler angles. The method to be described is easier and faster to use than Euler angle functions.

Although FIG. 5a represents a two dimensional space, it is equivalent to a three dimensional space where the rotation is around the Z axis. See FIG. 6a. The equations are:

$$X' = X^*COS(za) - Y^*SIN(za)$$
$$Y' = X^*SIN(za) + Y^*COS(za) \quad \text{Equation 1}$$

By symmetry the other equations are:

$$Z' = Z^*COS(ya) - X^*SIN(ya) \quad \text{Equation 2}$$
$$X' = Z^*SIN(ya) + X^*COS(ya)$$

See FIG. 6b.

and

$$Y' = Y^*COS(xa) - Z^*SIN(xa) \quad \text{Equation 3}$$
$$Z' = Y^*SIN(xa) + Z^*COS(xa)$$

See FIG. 6c.

From the ship's frame of reference it is at rest; it is the Universe that is rotating. We can either change the equations to make the angles negative or decide that positive rotations are clockwise. Therefore, from now on all positive rotations are clockwise.

Consolidating Equations 1, 2, and 3 for a motion consisting of rotations za (around the Z axis), ya (around the Y axis), and xa (around the X axis) yields:

X'=X*[COS(ya)*COS(za)]+Y*[-COS(ya)*SIN(za)]+Z*[SIN(ya)]

Y'=X*[SIN(xa)*SIN(ya)*COS(za)+COS(xa)*SIN(za)]+Y*[-SIN(xa)*SIN(ya)*SIN(za)+COS(xa)*COS(za)]+Z*[-SIN(xa)*COS(ya)]

Z'=X*[-COS(xa)*SIN(ya)*COS(za)+SIN(xa)*SIN(za)]+Y*[COS(xa)*SIN(ya)*SIN(za)+SIN(xa)*COS(za)]+Z*[COS(xa)*COS(ya)]

(The asymmetry in the equations is another indication of the difference the order of rotation makes.)

The main use of the consolidated equations is to show that any rotation will be in the form:

$$X'=Ax^*X+Bx^*Y+Cx^*Z$$

$$Y'=Ay^*X+By^*Y+Cy^*Z$$

$$Z'=Az^*X+Bz^*Y+Cz^*Z$$

If we start with three specific points in the initial, absolute coordinate system, such as:

Px=(1,0,0)

Py=(0,1,0)

Pz=(0,0,1)

after any number of arbitrary rotations,

Px'=(XA,YA,ZA)

Py'=(XB,YB,ZB)

Pz'=(XC,YC,ZC)

By inspection:

$$XA=Ax \quad XB=Bx \quad XC=Cx$$
$$YA=Ay \quad YB=By \quad YC=Cy$$
$$ZA=Az \quad ZB=Bz \quad ZC=Cz$$

Therefore, these three points in the ship's frame of reference provide the coefficients to transform the absolute coordinates of whatever is in the Universe of points. The absolute list of points is itself never changed so it is never lost and errors are not cumulative. All that is required is to calculate Px, Py, and Pz with sufficient accuracy. Px, Py, and Pz can be thought of as the axes of a gyrocompass or 3-axis stabilized platform in the ship that is always oriented in the original, absolute coordinate system.

TRANSLATIONS

Translations do not affect any of the angles and therefore do not affect the rotation coefficients. Translations will be handled as follows:

Rather than keep track of where the origin of the absolute coordinate system is from the ship's point of view (it changes with the ship's orientation), the ship's location will be kept track of in the absolute coordinate system.

To do this requires finding the inverse transformation of the rotation matrix. Px, Py, and Pz are vectors, each with a length of 1.000, and each one orthogonal to the others. (Rotating them will not change these properties.) The inverse of an orthonormal matrix (one composed of orthogonal unit vectors like Px, Py, and Pz) is formed by transposing rows and columns.

Therefore, for X, Y, Z in the Universe's reference and X', Y', Z' in the Ship's reference:

$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = \begin{bmatrix} Ax & Bx & Cx \\ Ay & By & Cy \\ Az & Bz & Cz \end{bmatrix} * \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \text{ and}$$

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} Ax & Ay & Az \\ Bx & By & Bz \\ Cx & Cy & Cz \end{bmatrix} * \begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix}$$

The ship's X unit vector (1,0,0), the vector which, according to the ship is straight ahead, transforms to (Ax,Bx,Cx). Thus the position of the ship in terms of the Universe's coordinates can be determined. The complete transformation for the Ship to look at the Universe, taking into account the position of the Ship: For X,Y,Z in Universe reference and X', Y', Z' in Ship's reference

$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = \begin{bmatrix} Ax & Bx & Cx \\ Ay & By & Cy \\ Az & Bz & Cz \end{bmatrix} * \begin{bmatrix} X-XT \\ Y-YT \\ Z-ZT \end{bmatrix}$$

INDEPENDENT OBJECTS

To draw objects in a polygon-based system, rotating the vertices that define the polygon will rotate the polygon.

The object will be defined in its own coordinate system (the object "library") and have associated with it a set of unit vectors. The object is rotated by rotating its unit vectors. The object will also have a position in the absolute Universe.

When we want to look at an object from any frame of reference we will transform each point in the object's library by applying a rotation matrix to place the object in the proper orientation. We will then apply a translation vector to place the object in the proper position. The rotation matrix is derived from both the object's and the observer's unit vectors; the translation vector is derived from the object's position, the observer's position, and the observer's unit vectors.

The simplest frame of reference from which to view an object is in the Universe's reference at (0,0,0) looking along the X axis. The reason is that we already have the rotation coeficients to look at the object. The object's unit vectors supply the matrix coefficients for the object to look at (rotate) the Universe. The inverse of this matrix will allow the Universe to look at (rotate) the object. As discussed previously, the unit vectors form an Orthonormal matrix; its inverse is simply the Transpose. After the object is rotated, it is translated to its position (its position according to the Universe) and projected. More on projection later.

A consequence of using the Unit Vector method is that, whatever orientation the object is in, it will always Roll, Pitch, and Yaw according to ITS axes.

For an object with unit vectors:

$$\begin{bmatrix} Ax & Bx & Cx \\ Ay & By & Cy \\ Az & Bz & Cz \end{bmatrix}$$

and absolute position [XT,YT,ZT], and [X,Y,Z] a point from the object's library, and [X',Y',Z'] in the Universe's reference, The Universe looks at the object:

$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = \begin{bmatrix} Ax & Ay & Az \\ Bx & By & Bz \\ Cx & Cy & Cz \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} XT \\ YT \\ ZT \end{bmatrix}$$

For two ships, each with unit vectors and positions:

$$\begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} \text{Ship 1 Unit Vectors}$$

(XT1,YT1,ZT1) Ship 1 Position

$$\begin{bmatrix} Ax2 & Bx2 & Cx2 \\ Ay2 & By2 & Cy2 \\ Az2 & Bz2 & Cz2 \end{bmatrix} \text{Ship 2 Unit Vectors}$$

(XT2,YT2,ZT2) Ship 2 Position

$$\begin{bmatrix} Ax2 & Ay2 & Az2 \\ Bx2 & By2 & Bz2 \\ Cx2 & Cy2 & Cz2 \end{bmatrix} \text{Transpose (Inverse) of Ship 2 Unit Vectors}$$

(X,Y,Z) in Ship 2 library, (X',Y',Z') in Universe Reference, and (X",Y",Z") in Ship 1 Reference Universe looks at ship 2:

$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = \begin{bmatrix} Ax2 & Ay2 & Az2 \\ Bx2 & By2 & Bz2 \\ Cx2 & Cy2 & Cz2 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} XT2 \\ YT2 \\ ZT2 \end{bmatrix}$$

Ship 1 looks at the Universe looking at Ship 2:

EQUATION 10

$$\begin{bmatrix} X'' \\ Y'' \\ Z'' \end{bmatrix} = \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} \cdot \begin{bmatrix} X'-XT1 \\ Y'-YT1 \\ Z'-ZT1 \end{bmatrix}$$

$$= \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} \cdot \begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} - \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} \cdot \begin{bmatrix} XT1 \\ YT1 \\ ZT1 \end{bmatrix}$$

Expand:

$$\begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} \cdot \begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} \cdot \left(\begin{bmatrix} Ax2 & Bx2 & Cx2 \\ Ay2 & By2 & Cy2 \\ Az2 & Bz2 & Cz2 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} XT2 \\ YT2 \\ ZT2 \end{bmatrix} \right)$$

Using the Distributive Law of Matrices:

$$= \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} \cdot \left(\begin{bmatrix} Ax2 & Ay2 & Az2 \\ Bx2 & By2 & Bz2 \\ Cx2 & Cy2 & Cz2 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \right) + \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} \cdot \begin{bmatrix} XT2 \\ YT2 \\ ZT2 \end{bmatrix}$$

Using the Associative Law of Matrices:

$$= \left(\begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} \cdot \begin{bmatrix} Ax2 & Ay2 & Az2 \\ Bx2 & By2 & Bz2 \\ Cx2 & Cy2 & Cz2 \end{bmatrix} \right) \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} \cdot \begin{bmatrix} XT2 \\ YT2 \\ ZT2 \end{bmatrix}$$

Substituting back into Equation 10 gives:

$$\begin{bmatrix} X'' \\ Y'' \\ Z'' \end{bmatrix} = \left(\begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} \cdot \begin{bmatrix} Ax2 & Ay2 & Az2 \\ Bx2 & By2 & Bz2 \\ Cx2 & Cy2 & Cz2 \end{bmatrix} \right) \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} \cdot \begin{bmatrix} XT2 \\ YT2 \\ ZT2 \end{bmatrix} - \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} \cdot \begin{bmatrix} XT1 \\ YT1 \\ ZT1 \end{bmatrix}$$

Therefore:

EQUATION 11

$$\begin{bmatrix} X'' \\ Y'' \\ Z'' \end{bmatrix} = \left(\begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} Ax2 & Ay2 & Az2 \\ Bx2 & By2 & Bz2 \\ Cx2 & Cy2 & Cz2 \end{bmatrix} \right) * \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} XT2 - XT1 \\ YT2 - YT1 \\ ZT2 - ZT1 \end{bmatrix}$$

Now let:

EQUATION 12

$$\begin{bmatrix} Ax & Bx & Cx \\ Ay & By & Cy \\ Az & Bz & Cz \end{bmatrix} = \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} Ax2 & Bx2 & Cx2 \\ Ay2 & By2 & Cy2 \\ Az2 & Bz2 & Cz2. \end{bmatrix}$$

This matrix represents the orientation of Ship 2 according to Ship 1's frame of reference. This concatentation needs to be done only once per update of Ship 2.

Also let:

EQUATION 13

$$\begin{bmatrix} XT \\ YT \\ ZT \end{bmatrix} = \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} XT2 - XT1 \\ YT2 - YT1 \\ ZT2 - ZT1) \end{bmatrix}$$

(XT,YT,ZT) is merely the position of Ship 2 in Ship 1's frame of reference.

This also needs to be done only once per update of Ship 2. Therefore the transformation to be applied to Ship 2's library will be of the form:

EQUATION 14

$$\begin{bmatrix} X'' \\ Y'' \\ Z'' \end{bmatrix} = \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} XT \\ YT \\ ZT \end{bmatrix}$$

Therefore, every object has six degrees of freedom, and any object may look at any other object.

SUMMARY OF TRANSFORMATION ALGORITHMS:

Define Unit Vectors: $|Px| = (Ax,Ay,Az)$

$|Py| = (Bx,By,Bz)$

$|Pz| = (Cx,Cy,Cz)$

Initialize: $Ax = By = Cz = 1.000$

$Ay = Az = Bx = Bz = Cx = Cy = 0$

If Roll;

$Ay' = Ay * COS(xa) - Az * SIN(za)$

$Az' = Ay * SIN(xa) + Az * COS(xa)$

$By' = By * COS(xa) - Bz * SIN(xa)$

$Bz' = By * SIN(xa) + Bz * COS(xa)$

$Cy' = Cy * COS(xa) - Cz * SIN(xa)$

$Cz' = Cy * SIN(xa) + Cz * COS(xa)$

If Pitch:

$Az' = Az * COS(ya) - Ax * SIN(ya)$

$Ax' = Az * SIN(ya) + Ax * COS(ya)$

$Bz' = Bz * COS(ya) - Bx * SIN(ya)$

$Bx' = Bz * SIN(ya) + Bx * COS(ya)$

$Cz' = Cz * COS(ya) - Cx * SIN(ya)$

$Cx' = Cz * SIN(ya) + Cx * COS(ya)$

If Yaw:

$Ax' = Ax * COS(za) - Ay * SIN(za)$

$Ay' = Ax * SIN(za) + Ay * COS(za)$

$Bx' = Bx * COS(za) - By * SIN(za)$

$By' = Bx * SIN(za) + By * COS(za)$

$Cx' = Cx * COS(za) - Cy * SIN(za)$

$Cy' = Cx * SIN(xa) + Cy * COS(xa)$

-continued

SUMMARY OF TRANSFORMATION ALGORITHMS:

('za', 'ya', and 'xa' are incremental rotations.)

The resultant unit vectors form a transformation matrix. For X, Y, Z in Universe reference and X', Y', Z' in Ship's reference

$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

and

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix}$$

The ship's x unit vector, the vector which according to the ship is straight ahead, transforms to (Ax,Bx,Cx). For a ship in free space, this is the acceleration vector when there is forward thrust. The sum of the accelerations determine the velocity vector and the sum of the velocity vectors determine the position vector (XT,YT,ZT). For two ships, each with unit vectors and positions:

$$\begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix}$$ Ship 1 Unit Vectors

(XT1,YT1,ZT1) Ship 1 Position

$$\begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix}$$ Ship 2 Unit Vectors

(XT2,YT2,ZT2) Ship 2 Position

Ship 1 looks at the Universe:

$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} X - XT \\ Y - YT \\ Z - ZT \end{bmatrix}$$

(X,Y,Z) in Universe
(X',Y',Z') in Ship 1 frame of reference

Ship 1 looks at Ship 2:

$$\begin{bmatrix} Ax & Bx & Cx \\ Ay & By & Cy \\ Az & Bz & Cz \end{bmatrix} = \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} Ax2 & Bx2 & Cx2 \\ Ay2 & By2 & Cy2 \\ Az2 & Bz2 & Cz2 \end{bmatrix}$$

(Ship 2 orientation relative to Ship 1 orientation)

$$\begin{bmatrix} XT \\ YT \\ ZT \end{bmatrix} = \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} XT2 - XT1 \\ YT2 - YT1 \\ ZT2 - ZT1 \end{bmatrix}$$

(Ship 2 position in Ship 1's frame of reference)

$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = \begin{bmatrix} Ax & Bx & Cx \\ Ay & By & Cy \\ Az & Bz & Cz \end{bmatrix} * \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} XT \\ YT \\ ZT \end{bmatrix}$$

(X,Y,Z) in Ship 2 library
(X',Y',Z') in Ship 1 reference

VISIBILITY AND ILLUMINATION

After a polygon is transformed, whether it is a terrain polygon or it belongs to an independently moving object such as another aircraft, the next step is to determine its illumination value, if indeed, it is visible at all.

Associated with each polygon is a vector of length 1 that is normal to the surface of the polygon. This is obtained by using the vector crossproduct between the vectors forming any two adjacent sides of the polygon. For two vectors V1=[x1,y1,z1] and V2=[x2,y2,z2] the crossproduct V1×V2 is the vector [(y1*z2−y2*z1),−(x1*z2−x2*z1),(x1*y2−x2*y1)]. The vector is then normalized by dividing it by its length. This gives it a length of 1. This calculation can be done when the data base is generated, becoming part of the data base, or it can be done during program run time. The tradeoff is between data base size and program execution time. In any event, it becomes part of the transformed data.

After the polygon and its normal are transformed to the aircraft's frame of reference, we need to calculate the angle between the polygon's normal and the vector from the base of the normal to the aircraft. This is done by taking the vector dot product. For two vectors V1=[x1,y1,z1] and V2=[x2,y2,z2], V1 dot V2=length(V1)*length(V2)*cos(a) and is calulated as (x1*x2+y1*y2+z1*z2). Therefore:

$$\cos(a) = \frac{(x1 * x2 + y1 * y2 + z1 * z2)}{\text{length}(V1) * \text{length}(V2)}$$

A cosine that is negative means that the angle is between 90 degress and 270 degrees. Since this angle is facing away from the observer it will not be visible and can be rejected and not subjected to further processing. The actual cosine value can be used to determine the brightness of the polygon for added realism.

CLIPPING

Now that the polygon has been transformed and checked for visibility it must be clipped so that it will properly fit on the screen after it is projected. Standard clipping routines are well known in the computer graphics industry. There are six clipping planes as shown in the 3D representation shown in FIG. 8*a* . The 2D top view is shown in FIG. 8*b*, and the 2D side view is shown in FIG. 8*c*. It should be noted that clipping a polygon may result in the creation of addition polygon sides which must be added to the polygon description sent to the polygon display routine.

PROJECTION

As shown in FIG. 7*a*, X' is the distance to the point along the X axis, Z' is the height of the point, Xs is the distance from the eyepoint to the screen onto which the point is to be projected, and Sy is the vertical displacement on the screen. Z'/X' and Sy/Xs form similar triangles so: Z'/X'=Sy/Xs, therefore Sy=Xs*Z'/X'. Likewise, Y'/X'=Sx/Xs so Sx=Xs*Y'/X' where Sx is the horizontal displacement on the screen. However, we still need to fit Sy and Sx to the monitor display coordinates. Suppose we have a screen that is 1024 by 1024. Each axis would be plus or minus 512 with (0,0) in the center. If we want a 90 degree field of view (plus or minus 45 degrees from the center), then when a point has Z'/X'=1 it must be put at the edge of the screen where its value is 512. Therefore Sy=512*Z'/X'. (Sy is the Screen Y-coordinate). Therefore:

Sy=K*Z'/X' Sy is the vertical coordinate on the display

Sx=K*Y'/X' Sx is the horizontal coordinate on the display

K is chosen to make the viewing angle fit the monitor coordinates. If K is varied dynamically we end up with a zoom lens effect. And if we are clever in implementing the divider, K can be performed without having to actually do a multiplication.

THE DATABASE

The data base is generated from several sources. The U.S. Geological Survey (USGS) makes available various databases, two of which are of particular interest. The first is the Digital Elevation Model data which consist of an array of regularly spaced terrain elevations. This data base is converted into a data base containing polygons (whose vertices are three-dimensional points) in order to maximize the geographic area covered by CD-ROM Data Base 105 and also to reduce the amount of run-time processing required of Computer 107. This is possible because there are large areas of terrain that are essentially flat. Note that flat does not necessarily mean level. A sloping area is flat without being level.

The Digital Elevation Model data elevations are spaced 30 meters apart. 30 meters=30m×39.37 in/m×1 ft/12 in=98.245 ft. A linear mile contains 5,280 ft/mi×1 data point/98.245 ft=53.65 data points/mi. Therefore, a square mile contains 53.65×53.65=2878 data points. California has a total area of 158,706 square miles which requires 158,706×2878=456,755,868 data points. Since this figure includes 2,407 sq mi of inland water areas, there are 2407×2878=6,927,346 data points just for inland water. The U.S. has a total area of 3,618,773 square miles which requires 3,618,773×2878=10,414,828,694 data points. This figure includes 79,484 sq mi of inland water areas requiring 79,484×2878=228,754,952 data points just for inland water.

The polygon data are organized in geographic data blocks. Because the amount of data in each geographic data block depends on the number of polygons and because the number of polygons depends on the flatness of the terrain, the size of each geographic data block is variable. Therefore, an address table is maintained that contains a pointer to each geographic data block. The first choice is to decide on the geographic area represented by the block. For the present invention the size is 20 mi×20 mi=400 sq mi. Therefore, the polygon data base for California requires 158,706 sq mi×1 block/400 sq mi=397 geographic data blocks. The number of polygons in a given geographic data block depends on the flatness of the terrain and what we decide is 'flat'. The definition of 'flatness' is that for a polygon whose vertices are three-dimensional points, there will be no elevation points that are higher than the plane of the polygon and there will be no elevation points that are below the the plane of the polygon by a distance called the Error Factor. A small Error Factor will require more polygons to represent a given terrain than will a large Error Factor. A small Error Factor will also generate the terrain more accurately. The Error Factor does not have to be the same for all Geographic Data Blocks. Blocks for areas of high interest, like airports and surrounding areas can be generated using a small Error Factor in order to represent the terrain more precisely. The present invention uses an Error Factor of 10 ft for areas surrounding airports and 50 ft for all other areas.

A procedure for generating the polygon data base from the Digital Elevation Model data is demonstrated in FIG. 12*a* through FIG. 12*f* and FIG. 13*a* through FIG. 13*f*. We start with three points which define a polygon and which has a surface. We select the next elevation point and decide if it belongs in the polygon accordinng to the citeria previously discussed. If it does, it gets added to the polygon. If not, not. We then test additional adjacent points until we run out. Then we start over with another three points.

When we are done generating polygons for a Geographic Data Block we go back and examine them; any polygon that is 'too big' is broken down into smaller polygons. This is to make sure there are always enough polygons on the screen to provide a proper reference for the pilot. (A single large polygon on the screen would not have any apparent motion.) Finally, the polygons are assigned colors and/or shades so that adjacent polygons will not blend into each other.

The other USGS data base used is the Digital Line Graph data which includes: political and administrative boundaries; hydrography consisting of all flowing water, standing water, and wetlands; major transportation systems consisting of roads and trails, railroads, pipelines, transmission lines, and airports; and significant manmade structures. The Digital Line Graph data is two-dimensional. In the present invention features such as water, roads, railroads, and pipelines are represented as polygons with elevations determined from the Digital Elevation Model data. Transmission lines and significant manmade structures are defined as three-dimensional objects made of polygons and are placed according to the elevations determined from the Digital Elevation Model data. The different types of objects are tagged so that by using Control Panel 106 the pilot can select them to be highlighted by category or by specific object. For example, the pilot can choose to have all airports highlighted or just the destination airport. The pilot can also choose to have a specific highway highlighted.

Data from additional digital data bases can also be incorporated. An example of such a data base is from Jeppesen Sanderson whose NavData Services division provides aeronautical charts and makes this information available in digital form.

While preferred embodiments of the present invention have been shown, it is to be expressly understood that modifications and changes may be made thereto and that the present invention is set forth in the following claims.

I claim:

1. A pilot aid which uses an aircraft's position and attitude to transform data from a digital data base to present a pilot with a synthesized three dimensional projected view of the world comprising:

a position determining system for locating said aircraft's position in three dimensions;

a digital data base comprising terrain data, said terrain data representing real terrestrial terrain as at least one polygon, said terrain data generated from elevation data of said real terrestrial terrain;

an attitude determining system for determining said aircraft's orientation in three dimensional space;

a computer to access said terrain data according to said aircraft's position and to transform said terrain data to provide three dimensional projected image data according to said aircraft's orientation; and

a display for displaying said three dimensional projected image data.

2. The pilot aid of claim 1, wherein said position determining system comprises a standard system for receiving and processing data from the global positioning system.

3. The pilot aid of claim 1, wherein said attitude determining system comprises a standard avionics system.

4. The pilot aid of claim 1, wherein said digital data base comprises a cd rom disc and cd rom drive.

5. The pilot aid of claim 1, further comprising a control panel to select at least one operating feature.

6. The pilot aid of claim 5, wherein said at least one operating feature comprises at least one feature selected from a group consisting of panning a viewpoint of said three dimensional projected image, tilting a viewpoint of said three dimensional projected image, zooming a viewpoint of said three dimensional projected image, and providing a three dimensional projected image of a route ahead.

7. The pilot aid as described in claim 1 wherein said digital data base further comprises structure data, said structure data representing manmade structures as one or more polygons.

8. The pilot aid as described in claim 1 wherein said elevation data comprises an array of elevation points, wherein each said polygon representing said terrain defines a plane, wherein in a first region of terrain represented by said at least one polygon each elevation point within each said polygon is within a first distance of said plane of each said polygon.

9. The pilot aid as described in claim 8 wherein in a second region of said terrain represented by said at least one polygon each elevation point within each said polygon is within a second distance of said plane of each said polygon in said second region, said second distance different from said first distance.

10. The pilot aid as described in claim 9 wherein no elevation point within each said polygon in said first region and said second region is above said plane of said polygon.

11. The pilot aid as described in claim 8 wherein no elevation point within each said polygon in said first region is above said plane of said polygon.

12. A pilot aid which uses an aircraft's position and attitude to transform data from a digital data base to present a pilot with a synthesized three dimensional projected view of the world comprising:

a position determining system for locating said aircraft's position in three dimensions;

a digital data base comprising terrain data, said terrain data representing real terrestrial terrain as at least one polygon, said terrain data generated from elevation data of said real terrestrial terrain;

an attitude determining system for determining said aircraft's orientation in three dimensional space;

a computer to access said terrain data according to said aircraft's position and to transform said terrain data to provide three dimensional projected image data according to said aircraft's orientation; and

a mass storage memory for recording said aircraft position data and said aircraft's attitude data for allowing a flight of said aircraft over said terrain to be displayed at a later time.

13. The pilot aid of claim 12, wherein said position determining system comprises a standard system for receiving and processing data from the global positioning system.

14. The pilot aid of claim 12, wherein said attitude determining systems comprises a standard avionics system.

15. The pilot aid of claim 12, wherein said digital data base comprises a cd rom and a cd rom drive.

16. The pilot aid of claim 12, further comprising a control panel to select at least one operating feature.

17. The pilot aid of claim 16, wherein said at least one operating feature comprises at least one feature selected from a group consisting of panning a viewpoint of said three dimensional projected image, tilting a viewpoint of said three dimensional projected image, zooming a viewpoint of said three dimensional projected image, providing a three dimensional projected image of a route ahead, and providing a three dimensional projected image of a previous flight.

18. The pilot aid as described in claim 12 wherein said digital data base further comprises structure data, said struc-

ture data representing manmade structures as one or more polygons.

19. The pilot aid as described in claim 12 wherein said elevation data comprises an array of elevation points, wherein each said polygon representing said terrain defines a plane, wherein in a first region of terrain represented by said at least one polygon each elevation point within each said polygon is within a first distance of said plane of each said polygon.

20. The pilot aid as described in claim 19 wherein in a second region of said terrain represented by said at least one polygon each elevation point within each said polygon is within a second distance of said plane of each said polygon in said second region, said second distance different from said first distance.

21. The pilot aid as described in claim 20 wherein no elevation point within each said polygon in said first region and said second region is above said plane of said polygon.

22. The pilot aid as described in claim 19 wherein no elevation point within each said polygon in said first region is above said plane of said polygon.

23. A pilot aid which uses an aircraft's position and attitude to transform data from a digital data base to present a pilot with a synthesized three dimensional projected view of the world comprising:

- a position determining system for locating said aircraft's position in three dimensions;
- a digital data base comprising terrain data, said terrain data representing real terrestrial terrain as at least one polygon, said terrain data generated from elevation data of said real terrestrial terrain;
- a first attitude determining system for determining said aircraft's orientation in three dimensional space;
- a head mounted display worn by said pilot of said aircraft;
- a second attitude determining system for determining the orientation of said pilot's head in three dimensional space; and
- a computer to access said terrain data according to said aircraft's position and to transform said terrain data to provide three dimensional projected image data to said head mounted display according to said aircraft's orientation and said pilot head orientation.

24. The pilot aid as described in claim 23 wherein said digital data base further comprises structure data, said structure data representing manmade structures as one or more polygons.

25. The pilot aid as described in claim 23 wherein said elevation data comprises an array of elevation points, wherein each said polygon representing said terrain defines a plane, wherein in a first region of terrain represented by said at least one polygon each elevation point within each said polygon is within a first distance of said plane of each said polygon.

26. The pilot aid as described in claim 25 wherein in a second region of said terrain represented by said at least one polygon each elevation point within each said polygon is within a second distance of said plane of each said polygon in said second region, said second distance different from said first distance.

27. The pilot aid as described in claim 26 wherein no elevation point within each said polygon in said first region and said second region is above said plane of said polygon.

28. The pilot aid as described in claim 25 wherein no elevation point within each said polygon in said first region is above said plane of said polygon.

29. A method of using an aircraft's position and attitude to transform data from a digital data base to present a pilot with a synthesized three dimensional projected view of the world comprising:

- locating said aircraft's position in three dimensions;
- providing a data base comprising terrain data, said terrain data representing real terrestrial terrain as at least one polygons, said terrain data generated from elevation data of said real terrestrial terrain;
- determining said aircraft's orientation in three dimensional space;
- accessing said terrain data according to said aircraft's position;
- transforming said terrain data to provide three dimensional projected image data according to said aircraft's orientation; and
- displaying said three dimensional projected image data.

30. The method of claim 29 further comprising selecting at least one operating feature, wherein said at least one operating feature comprises at least one feature selected from a group consisting of panning a viewpoint of said three dimensional projected image, tilting a viewpoint of said three dimensional projected image, zooming a viewpoint of said three dimensional projected image, and presenting a three dimensional projected image of a route ahead.

31. The method as described in claim 29 wherein said terrain data base is produced by a method comprising the steps of:

- providing a plurality of elevation points, each of said plurality of elevation points representing an elevation of a point on a terrain;
- defining a polygon having at least one vertex defined by at least one of said elevation points;
- examining an adjacent one of said plurality of elevation points to determine if expanding said polygon to an expanded polygon to include said adjacent one of said plurality of elevation points causes at least one of said plurality of elevation points within said expanded polygon not to be within a first distance of a plane of said expanded polygon; and
- expanding said polygon to include said adjacent one of said plurality of elevation points if each of said elevation points within said expanded polygon is within said first distance of said plane.

32. The method as described in claim 31 wherein at least one additional adjacent one of said plurality of elevation points is examined, and wherein said polygon is expanded to include said at least one additional one of said plurality of elevation points that does not cause any of said elevation points within said expanded polygon not to be within said first distance of said plane of said expanded polygon.

33. The method as described in claim 32 wherein said polygon is stored in said terrain data base after all of said elevation points adjacent to said polygon have been examined.

34. The method as described in claim 32 wherein additional polygons are defined, expanded, and added to said terrain database.

35. The method as described in claim 31 wherein at least one additional adjacent one of said plurality of elevation points is examined, and wherein said polygon is expanded to include said at least one additional one of said plurality of elevation points that does not cause any of said elevation points within said expanded polygon to be above said plane of said expanded polygon and does not cause any of said elevation points within said expanded polygon not to be within said first distance of said plane of said expanded polygon.

36. The method as described in claim 35 wherein said polygon is stored in said terrain data base after all of said elevation points adjacent to said polygon have been examined.

37. The method as described in claim 31 wherein said adjacent one of said plurality of elevation points is further examined to determine if at least one of said plurality of elevation points within said expanded polygon is above said plane of said expanded polygon, and said polygon is expanded if none of said elevation points within said expanded polygon is above said plane of said expanded polygon and if each of said elevation points within said expanded polygon is within said first distance of said plane.

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PATENT APPLICATION SERIAL NO. 274394

U.S. DEPARTMENT OF COMMERCE
PATENT AND TRADEMARK OFFICE
FEE RECORD SHEET

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ABSTRACT

A pilot aid using synthetic reality consists of a ~~means for determining~~ way to determine the aircraft's position and attitude such as by the global positioning system (GPS), a digital data base containing three-dimensional polygon data for terrain and manmade structures, a computer, and a display. The computer uses the aircraft's position and attitude to look up the terrain and manmade structure data in the data base and by using standard computer graphics methods creates a projected three-dimensional scene on a cockpit display. This presents the pilot with a synthesized view of the world regardless of the actual visibility. A second embodiment uses a head-mounted display with a head position sensor to provide the pilot with a synthesized view of the world that responds to where he or she is looking and which is not blocked by the cockpit or other aircraft structures. A third embodiment allows the pilot to preview the route ahead or to replay previous flights.

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Patent Application of

Jed Margolin

for

PILOT AID USING A SYNTHETIC ~~REALITY~~ ENVIRONMENT

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BACKGROUND OF THE INVENTION

This invention relates to a pilot aid for synthesizing a view of the world. When flying under Visual Flight Rules (VFR) the normal procedure for determining your position is to relate what you see out the window to the information on a paper map. During the day it can be difficult to determine your location because the desired landmark can be lost in the clutter of everything else. When flying at night you see mostly lights. When flying under Instrument Flight Rules (IFR) you must relate the information from various navigation aids to the information on a printed map. You must then interpret the map information in order to avoid flying into objects such as mountains and the like. An improvement in this situation came about when the global positioning system (GPS) became operational and available for civilian use. GPS directly provides map coordinates but you must still, however, interpret the map information. Systems have been developed which use GPS coordinates to access an electronic map which is presented on a display as a flat map. Systems have also been developed that present an apparent three-dimensional effect and some that present a mathematically correct texture-mapped three-dimensional projected display.

Both of these systems require a very large amount of storage for terrain data. The latter system also requires specialized hardware. Their high cost have prevented their widespread adoption by the avaiation community.

The 1984 patent to Taylor et al. (U.S. Patent No. 4,445,118) shows the basic operation of the global positioning system (GPS).

The 1984 patent to Johnson et al. (U.S. Patent No. 4,468,793) shows a receiver for receiving GPS signals.

The 1984 patent to Maher (U.S. Patent No. 4,485,383) shows another receiver for receiving GPS signals.

The 1986 patent to Evans (U.S. Patent No. 4,599,620) shows a method for determining the orientation of a moving object and producing roll, pitch, and yaw information.

The 1992 patent to Timothy et al. (U.S. Patent No. 5,101,356) also shows a method for determining the orientation of a moving object and producing roll, pitch, and yaw information.

The 1993 patent to Ward et al. (U.S. Patent No. 5,185,610) shows a method for determining the orientation of a moving object from a single GPS receiver and producing roll, pitch, and yaw information.

The 1992 patent to Fraughton et al. (U.S. Patent No. 5,153,836) shows a navigation, surveillance, emergency location, and collision avoidance system and method whereby each craft determines its own position using LORAN or GPS and transmits it on a radio channel along with the craft's identification information. Each craft also receives the radio channel and thereby can determine the position and identification of other craft in the vicinity.

The 1992 patent to Beckwith et al. (U.S. Patent No. 5,140,532) provides a topographical two-dimensional real-time display of the terrain over which the aircraft is passing, and a slope-shading technique incorporated into the system provides to the display an apparent three-dimensional effect similar to that provided by a relief map. This is accomplished by reading compressed terrain data from a cassette tape in a controlled manner based on the instantaneous geographical location of the aircraft as provided by the aircraft navigational computer system, reconstructing the compressed data by suitable processing and writing the reconstructed data into a scene memory with a north-up orientation. A read control circuit then controls the read-out of data from the scene memory with a heading-up orientation to provide a real-time display of the terrain over which the aircraft is passing. A symbol at the center of display position depicts the location of the aircraft with respect to the terrain, permitting the pilot to navigate the aircraft even under conditions of poor visibility. However, the display provided by this system is in the form of a moving map rather than a true perspective display of the terrain as it would appear to the pilot through the window of the aircraft.

The 1987 patent to Beckwith et al. (U.S. Patent No. 4,660,157) is similar to U.S. Patent No. 5,140,532. It also reads compressed terrain data from a cassette tape in a controlled manner based on the instantaneous geographical location of the aircraft as provided by the aircraft navigational computer system and reconstructs the compressed data by suitable processing and writing the reconstructed data into a scene memory. However, instead of providing a topographical two-dimensional display of the terrain over which the aircraft is passing and using a slope-shading technique to provide an apparent three-dimensional effect similar to that provided by a relief map as shown in the '532 patent, the '157 patent processes the data to provide a 3D perspective on the display. There are a number of differences between the '157 patent and the present invention:

1. The '157 Patent stores the map as a collection of terrain points with associated altitudes; the large amount of storage required by this approach requires that a tape be prepared for each mission.
   The present invention stores terrain data as a collection of polygons which results in a significant reduction of data base storage; larger geographic areas can be stored so that it it not necessary to generate

a data base for each mission.

2. The '157 Patent uses a tape cassette for data base storage; the long access time for tape storage makes it necessary to use a relatively large cache memory. The present invention uses a CD-ROM which permits random access to the data so that the requirements for cache storage are reduced.
3. The '157 Patent accounts for the aircraft's heading by controlling the way the data is read out from the tape. Different heading angles result in the data being read from a different sequence of addresses. Since addresses exist only at discrete locations, the truncation of address locations causes an unavoidable change in the map shapes as the aircraft changes heading. The present invention stores terrain as polygons which are mathematically rotated as the aircraft changes attitude. The resolution is determined by number of bits used to represent the vertices of the polygons, not the number of storage addresses.
4. The '157 accounts for the roll attitude of the aircraft by mathematically rotating the screen data after it is projected. The '157 Patent does not show the display being responsive to the pitch angle of the aircraft. In systems such as this the lack of fidelity is apparent to the user. People know what things are supposed to look like and how they are supposed to change perspective when they move. The present invention uses techniques that have long been used by the computer graphics industry to perform the mathematically correct transformation and projection.
5. The '157 shows only a single cockpit display while one of the embodiments of the present invention shows a stereographic head-mounted display with a head sensor. The pilot is presented with a synthesized view of the world that is responsive to wherever the pilot looks; the view is not blocked by the cockpit or other aircraft structures. This embodiment is not anticipated by the '157 patent.

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The 1991 patent to Behensky et al. (U.S. Patent No. 5,005,148) shows a driving simulator for a video game. The road and other terrain are produced by mathematically transforming a three-dimensional polygon data base.

The first sales brochure from Atari Games Corp. is for a coin-operated game (Hard Drivin') produced in 1989 and relates to the '148 patent. The terrain is represented by polygons in a three-dimensional space. Each polygon is transformed mathematically according to the position and orientation of the player. After being tested to determine whether it is visible and having the appropriate illumination function performed, it is clipped and projected onto the display screen. These operations are in general use by the computer graphics industry and are well known to those possessing ordinary skill in the art.

The second sales brochure from Atari Games Corp. is for a coin-operated game (Steel Talons) produced in 1991 and which also relates to the '148 patent and the use of polygons to represent terrain and other objects.

The 1993 patent to Dawson et al. (U.S. Patent No. 5,179,638) shows a a method and apparatus for providing a texture mapped perspective view for digital map systems which includes a geometry engine that receives the elevation posts scanned from the cache memory by the shape address generator. A tiling engine is then used to transform the elevation posts into three-dimensional polygons. There are a number of differences between the '638 patent and the present invention:

1. The '638 Patent is for a digital map system only. The matter of how the location and attitude are selected is not addressed. The present invention uses a digital map as part of a system for presenting an aircraft pilot with a synthesized view of the world regardless of the actual visibility.
2. The '638 Patent stores the map as a collection of terrain points with associated altitudes, thereby requiring a large amount of data storage.

The terrain points are transformed into polygons during program run-time, thereby adding to the processing burden. The present invention stores terrain data as a collection of polygons which results in a significant reduction of data base storage.

3. The present invention also teaches the use of a stereographic head-mounted display with a head sensor. The pilot is presented with a synthesized view of the world that is responsive to wherever the pilot looks; the view is not blocked by the cockpit or other aircraft structures. This embodiment is not anticipated by the '638 patent.

The 1994 patent to Hamilton et al. (U.S. Patent No. 5,296,854) shows a helicopter virtual display system in which the structual outlines corresponding to structual members forming the canopy structure are added to the head-up display in order to replace the canopy structure clues used by pilots which would otherwise be lost by the use of the head-up display.

The 1994 patent to Lewins (U.S. Patent No. 5,302,964) shows a head-up display for an aircraft and incorporates a cathode-ray tube image generator with a digital look-up table for distortion correction. An optical system projects an image formed on the CRT screen onto a holographic mirror combiner which is transparent to the pilot's direct view through the aircraft windshield.

The sales brochure from the Polhemus company shows the commercial availability of a position and orientation sensor which can be used on a head-mounted display.

The article from EDN magazine, January 7, 1993, pages 31-42, entitled "System revolutionizes surveying and navigation" is an overview of how the global positioning system (GPS) works and lists several manufacturers of commercially available receivers. The article also mentions several applications such as the use by geologists to monitor fault lines, by oil companies for off-shore oil explorations, for keeping track of lower-orbit satellites, by fleet vehicle operators to keep track of their fleet, for crop sprayers to spread fertilizer and pesticides more efficiently, and for in-car systems to display maps for automotive navigation.

The section from "Aviator's Guide to GPS" presents a history of the GPS program.

The sales brochure from Megellan Systems Corp. is for commercially available equipment comprising a GPS receiver with a moving map display. The map that is displayed is a flat map.

The sales brochure from Trimble Navigation is for a commercially available GPS receiver.

The sales brochure from the U.S. Geological ~~Service~~ survey shows the availability of Digital Elevation Models for all of the United States and its territories.

The second sales brochure from the U.S. Geological ~~Service~~ survey shows the availability of Digital Line Graph Models for all of the United States and its territories. The data includes: political and administrative boundaries; hydrography consisting of all flowing water, standing water, and wetlands; major transportation systems consisting of roads and trails, railroads, pipelines, transmission lines, and airports; and significant manmade structures.

The Washington Sectional Aeronautical Chart is a paper map published by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration that shows the complexity of the information that an aircraft pilot needs in order to fly in the area covered by the map. The other areas of the U.S. are covered by similar maps.

The sales brochure from Jeppesen Sanderson shows that the company makes its navigation data base available in computer readable form.

Accordingly, several objects and advantages of my invention are to provide a system that produces a mathematically correct three-dimensional projected view of the terrain while reducing the amount of storage required for the data base and which can be accomplished by using standard commercially available components. The invention can be used as a real-time inflight aid or it can be used to preview a flight, or it can be used to replay and review a previous flight.

Further objects and advantages of my invention will become apparant from a consideration of the drawings and ensuing description.

SUMMARY OF THE INVENTION

The present invention is a pilot aid which uses the aircraft's position and attitude to transform data from a digital data base to present a pilot with a synthesized three-dimensional projected view of the world. The three-dimensional position is typically determined by using the output of a commercially available GPS receiver. As a safety check, the altitude calculated by the GPS receiver can be compared to the output of either a standard altimeter or a radio altimeter. Attitude can also be determined from the use of a GPS receiver or it can be derived from standard avionic instruments such as turn-and-bank indicator and gyrocompass. The digital data base represents the terrain and manmade structures as collections of polygons in order to minimize storage requirements. The pilot can select several feature such as pan, tilt, and zoom which would allow the pilot to see a synthesized view of terrain that would otherwise be blocked by the aircraft's structure, especially on a low-wing aircraft. The pilot can also preview the route either inflight or on the ground. Because the system has the ability to save the flying parameters from a flight, the pilot can replay all or part of a previous flight, and can even take over during the replay to try out different flight strategies. Through the use of a head-mounted display with a head sensor, the pilot can have complete range of motion to receive a synthesized view of the world, completely unhindered by the aircraft structure.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram showing the output to a single video display.

FIG. 2 is a block diagram showing the output to a head-mounted display.

FIG. 3 is a block diagram showing a system used to plan and/or replay a particular flight.

FIG. 4 is a block diagram showing Computer 107 and Graphics System 108 in FIG. 1, FIG. 2, and FIG. 3.

FIG. 5a shows a simple positive (counter-clockwise) rotation of a point around the origin of a 2-Dimensional space.

FIG. 5b shows a second positive (counter-clockwise) rotation of a point around the origin of a 2-Dimensional space.

FIG. 6a shows the equivalent three dimensional space of FIG. 5a where the rotation is around the Z axis.

FIG. 6b is a re-orientation of the axes of FIG. 6a showing rotation around the Y axis.

FIG. 6c is a re-orientation of the axes of FIG. 6a showing rotation around the X axis.

FIG. 7a is a side view showing the projection of a point in three-dimensions projected onto a two-dimensional screen.

FIG. 7b is a top view showing the projection of a point in three-dimensions projected onto a two-dimensional screen.

FIG. 8a is a cabinet-projected three-dimensional representation of the viewing pyramid.

FIG. 8b is a 2D top view of the viewing pyramid.

FIG. 8c is a 2D side view of the viewing pyramid.

FIG. 9a shows an unclipped polygon.

FIG. 9b shows how clipping the polygon in FIG. 9a produces additional sides to the polygon.

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FIG. 10a shows the impending crossover from Geographic Data Block 21 to Geographic Data Block 22.

FIG. 10b shows the result of a crossover from Geographic Data Block 21 to Geographic Data Block 22.

FIG. 11a shows the impending crossover from Geographic Data Block 22 to Geographic Data Block 32.

FIG. 11b shows the result of a crossover from Geographic Data Block 22 to Geographic Data Block 32.

FIG. 12a through FIG. 12e, and FIG. 13a through FIG. 13e show the procedure for generating the polygon data base from the Digital Elevation Model data.

DETAILED SPECIFICATION

FIG. 1 shows the basic form of the invention. GPS Receiver 101 receives signals from the satellites that make up the global positioning system (GPS) and calculates the aircraft's position in three dimensions. Altimeter 104 provides an output of the aircraft's altitude as a safety check in the event GPS Receiver 101 malfunctions. Turn-and-bank Indicator 102 and Gyrocompass 103 provide the aircraft's attitude which comprises heading, roll, and pitch. CD-ROM Data Base 105 contains the digital data base consisting of three-dimensional polygon data for terrain and manmade structures.

Computer 107 is shown in more detail in FIG. 4 and uses commercially available integrated circuits including processor 404, the MPC601, from Motorola Semiconductor Inc. The MPC601 is a fast 32-bit RISC processor with a floating point unit and a 32K Byte eight-way set-associative unified instruction and data cache. Most integer instructions are executed in one clock cycle. Compilers are available for ANSI standard C and for ANSI standard FORTRAN 77. Computer 107 also contains ROM 405, RAM 406, Avionics Interface 401, CD-ROM Interface 402, Control Panel Interface 403, Graphics Systems Interface 407, and Hard Drive Interface 408.

Computer 107 uses the aircraft's position from GPS Receiver 101 to look up the terrain and manmade structure data in CD-ROM Data Base 105. This data is organized in geographic blocks and is accessed so that there is always the proper data present. This is shown in FIG. 10a. FIG. 10b shows that when the aircraft crosses from Block 21 to Block 22, the data from Blocks 10, 20, and 30 are discarded and data from Blocks 13, 23, and 33 are brought in from CD-ROM Data Base 105. FIG. 11a and FIG. 11b show the aircraft crossing from Block 22 to Block 32.

Computer 107 uses the aircraft's position from GPS Receiver 101 and attitude information from Turn-and-bank Indicator 102 and Gyrocompass 103 to mathematically operate on the terrain and manmade structure data to present three-dimensional projected polygons to Graphics System 108. As shown in FIG. 4, Graphics System 108 consists of a commercially available graphics integrated circuit 409, the 86C805, made by S3 Incorporated. This integrated circuit contains primitives for drawing lines in addition to the standard SVGA graphics functions. The 86C805 controls DRAM 410 which is the video memory consisting of two buffers of 1024 x 768 pixels, each of which is 8 bits deep. The video to be displayed from DRAM 410 is sent to RAMDAC 411 which is an integrated circuit commercially available from several manufacturers, such as Brooktree and AT&T. RAMDAC 411 contains a small RAM of 256 x 24 bits and three 8-bit DACs. The RAM section is a color table programmed to assign the desired color to each of the 256 combinations possible by having 8 bits/pixel and is combined with three video DACs, one for each color for Video Display 109.

Video Display 109 is a color video display of conventional design such as a standard CRT, an LCD panel, or a plasma display panel. The preferred size of Video Display 109 is 19" although other sizes may be used.

FIG. 2 shows the use of the system with Head Mounted Display 201. Head Mounted Display Attitude Sensors 202 provide Computer 107 with the orientation of Head Mounted Display 201. This orientation is concatenated with the aircraft's orientation provided by Turn-and-bank Indicator 102 and Gyrocompass 103. As a consequence the pilot can turn his or her head and view the three-dimensional synthesized view of the transformed terrain and manmade structure data unhindered by the aircraft's structure. With the appropriate sensors for engines, fuel tanks, doors, and the like, the pilot can be presented with synthesized representations of these objects in their correct locations. For example, the pilot would be able to 'look' at a fuel-tank and 'see' if it is running low. The pilot would also be able to 'see' if there is a problem with an engine and, on multi-engine aircraft, identify which one. By using a technique similar to that taught in the 1992 patent to Fraughton et al. (U.S. Patent No. 5,153,836) where each aircraft determines its own position using LORAN or GPS and transmits it on a radio channel along with the aircraft's identification information so that each craft also receives the radio channel and can thereby determine the position and identification of other craft in the vicinity, these other aircraft can be presented in the present invention as three-dimensional objects in their correct positions to alert the pilot to their presence and take evasive maneuvers as required.

Hard Disk Drive 110 is for recording the aircraft's position and orientation data for later playback in order to review the flight. Because the information presented on Video Display 109 is a function of the aircraft's position and orientation data applied to the CD-ROM Data Base 105, it can be reconstructed later at any time by storing just the aircraft's position and orientation data and applying it again to CD-ROM Data Base 106, as long as the data base is still available. The aircraft's position and orientation data requires fewer than 100 bytes. By recording it every 0.1 seconds, an hour requires about 3.6 Megabytes of storage. (100 bytes/update x 10 updates/second x 60 seconds/min x 60 minutes/hour = about 3.6 Megabytes) Therefore, a standard 340 Megabyte hard drive would store about 94 hours of operation.

A method for previewing a route that has not been flown before is shown in FIG. 3 . GPS Receiver 101, Turn-and-bank Indicator 102, Gyrocompass 103, and Altimeter 104 are replaced by User Flight Controls with Force Feedback 301 and Aerodynamic Model Processor 302. Aerodynamic Model Processor 302 is a processor that implements the aerodynamic mathematical model for the type of aircraft desired. It receives the user inputs from User Flight Control with Force Feedback 301, performs the mathematical calculations to simulate the desired aircraft, and supplies output back to the Force Feedback part of

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the controls and to Computer 107. The outputs supplied to Computer 107 simulate the outputs normally supplied to GPS Receiver 101, Turn-and-bank Indicator 102, Gyrocompass 103, and Altimeter 104. In this way, Computer 107 executes exactly the same program that it would perform in the in-flight system. This permits the pilot to practice flying routes that he or she has not flown before and is particularly useful in practicing approach and landing at unfamiliar airports. This system does not need to be installed in an aircraft; it can be installed in any convenient location, even the pilot's home.

Control Panel ~~104~~ 106 allows the pilot to select different operating features. For example, the pilot can choose the 'look angle' of the display (pan and tilt). This would allow the pilot to see synthesized terrain coresponding to real terrain that would otherwise be blocked by the aircraft's structure like the nose, or the wing on a low wing aircraft. Another feature is the zoom function which provides magnification. Another feature is to permit the pilot to select a section of the route other than the one he or she is on, for example, to preview the approach to the destination airport.

MATH INTRO

The math for the present invention has been used in the field of coin-operated video games and in traditional computer graphics. However, since it has not been well documented, it will be presented here. The basic concept assumes the unit is a simulator, responsive ~~the~~ to the user's inputs. It is a short step from that to the present invention where the inputs represent the physical location and attitude of the aircraft.

The steps required to view a 3D polygon-based data base are:

1. Transformation (translation and rotation as required)
2. Visibility and illumination
3. Clipping
4. Projection

In this geometric model there is an absolute Universe filled with Objects, each of which is free to rotate and translate. Associated with each Object is an Orthonormal Matrix (i.e. a set of Orthogonal Unit Vectors) that decribes the Object's orientation with respect to the Universe. Because the Unit Vectors are Orthogonal, the Inverse of the matrix is simply the Transpose. This makes it very easy to change the point of reference. The Object may look at the Universe or the Universe may look at the Object. The Object may look at another Object after the appropriate concatenation of Unit Vectors. Each Object will always Roll, Pitch, or Yaw around its own axes regardless of its current orientation without using Euler angle functions.

ROTATIONS

The convention used here is that the Z axis is straight up, the X axis is straight ahead, and the Y axis is to the right. ROLL is a rotation around the X axis, PITCH is a rotation around the Y axis, and YAW is a rotation around the Z axis.

For a simple positive (counter-clockwise) rotation of a point around the origin of a 2-Dimensional space:

$$X' = X*COS(a) - Y*SIN(a)$$
$$Y' = X*SIN(a) + Y*COS(a)$$

See FIG. 5a.

If we want to rotate the point again there are two choices:

1. Simply sum the angles and rotate the original points, in which case:

$$X'' = X*COS(a+b) - Y*SIN(a+b)$$
$$Y'' = X*SIN(a+b) + Y*COS(a+b)$$

2. Rotate X', Y' by angle b:

$$X'' = X'*COS(b) - Y'*SIN(b)$$
$$Y'' = X'*SIN(b) + Y'*COS(b)$$

See FIG. 5b.

With the second method the errors are cumulative. The first method preserves the accuracy of the original coordinates; unfortunately it works only for rotations around a single axis. When a series of rotations are done together around two or three axes, the order of rotation makes a difference. As an example: An airplane always Rolls, Pitches, and Yaws according to its own axes. Visualize an airplane suspended in air, wings straight and level, nose pointed North. Roll 90 degrees clockwise, then pitch 90 degrees "up". The nose will be pointing East. Now we will start over and reverse the order of rotation. Start from straight and level, pointing North. Pitch up 90 degrees, then Roll 90 degrees clockwise, The nose will now be pointing straight up, where "up" is referenced to the ground. If you have trouble visualizing these motions, just pretend your hand is the airplane.

This means that we cannot simply keep a running sum of the angles for each axis. The standard method is to use functions of Euler angles. The method to be described is easier and faster to use than Euler angle functions.

Although FIG. 5a represents a two dimensional space, it is equivalent to a three dimensional space where the rotation is around the Z axis. See FIG. 6a. The equations are :

$$X' = X*\mathrm{COS}(za) - Y*\mathrm{SIN}(za) \qquad \text{Equation 1}$$
$$Y' = X*\mathrm{SIN}(za) + Y*\mathrm{COS}(za)$$

By symmetry the other equations are:

$$Z' = Z*\mathrm{COS}(ya) - X*\mathrm{SIN}(ya) \qquad \text{Equation 2}$$
$$X' = Z*\mathrm{SIN}(ya) + X*\mathrm{COS}(ya)$$

See FIG. 6b.

and

$$Y' = Y*\mathrm{COS}(xa) - Z*\mathrm{SIN}(xa) \qquad \text{Equation 3}$$
$$Z' = Y*\mathrm{SIN}(xa) + Z*\mathrm{COS}(xa)$$

See FIG. 6c.

From the ship's frame of reference it is at rest; it is the Universe that is rotating. We can either change the equations to make the angles negative or decide that positive rotations are clockwise. Therefore, from now on all positive rotations are clockwise.

Consolidating Equations 1, 2, and 3 for a motion consisting of rotations za (around the Z axis), ya (around the Y axis), and xa (around the X axis) yields:

$$X' = X*[\mathrm{COS}(ya)*\mathrm{COS}(za)] +$$
$$Y*[-\mathrm{COS}(ya)*\mathrm{SIN}(za)] +$$
$$Z*[\mathrm{SIN}(ya)]$$

$$Y' = X*[\mathrm{SIN}(xa)*\mathrm{SIN}(ya)*\mathrm{COS}(za)+\mathrm{COS}(xa)*\mathrm{SIN}(za)] +$$
$$Y*[-\mathrm{SIN}(xa)*\mathrm{SIN}(ya)*\mathrm{SIN}(za) + \mathrm{COS}(xa)*\mathrm{COS}(za)] +$$
$$Z*[-\mathrm{SIN}(xa)*\mathrm{COS}(ya)]$$

$$Z' = X*[-\mathrm{COS}(xa)*\mathrm{SIN}(ya)*\mathrm{COS}(za) + \mathrm{SIN}(xa)*\mathrm{SIN}(za)] +$$
$$Y*[\mathrm{COS}(xa)*\mathrm{SIN}(ya)*\mathrm{SIN}(za) + \mathrm{SIN}(xa)*\mathrm{COS}(za)] +$$
$$Z*[\mathrm{COS}(xa)*\mathrm{COS}(ya)]$$

(The asymmetry in the equations is another indication of the difference the order of rotation makes.)

The main use of the consolidated equations is to show that any rotation will be in the form:

$$X' = Ax * X + Bx * Y + Cx * Z$$
$$Y' = Ay * X + By * Y + Cy * Z$$
$$Z' = Az * X + Bz * Y + Cz * Z$$

If we start with three specific points in the initial, absolute coordinate system, such as:

$$Px = (1,0,0)$$
$$Py = (0,1,0)$$
$$Pz = (0,0,1)$$

after any number of arbitrary rotations,

$$Px' = (XA,YA,ZA)$$
$$Py' = (XB,YB,ZB)$$
$$Pz' = (XC,YC,ZC)$$

By inspection:

XA=Ax	XB=Bx	XC=Cx
YA=Ay	YB=By	YC=Cy
ZA=Az	ZB=Bz	ZC=Cz

Therefore, these three points in the ship's frame of reference provide the coefficients to transform the absolute coordinates of whatever is in the Universe of points. The absolute list of points is itself never changed so it is never lost and errors are not cumulative. All that is required is to calculate Px, Py, and Pz with sufficient accuracy.

Px, Py, and Pz can be thought of as the axes of a gyrocompass or 3-axis stabilized platform in the ship that is always oriented in the original, absolute coordinate system.

TRANSLATIONS

Translations do not affect any of the angles and therefore do not affect the rotation coefficients. Translations will be handled as follows:

Rather than keep track of where the origin of the absolute coordinate system is from the ship's point of view (it changes with the ship's orientation), the ship's location will be kept track of in the absolute coordinate system.

To do this requires finding the inverse transformation of the rotation matrix. Px, Py, and Pz are vectors, each with a length of 1.000, and each one orthogonal to the others. (Rotating them will not change these properties.) The inverse of an orthonormal matrix (one composed of orthogonal unit vectors like Px, Py, and Pz) is formed by transposing rows and columns.

Therefore, for X, Y, Z in the Universe's reference and X', Y', Z' in the Ship's reference:

TO210X

$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = \begin{bmatrix} Ax & Bx & Cx \\ Ay & By & Cy \\ Az & Bz & Cz \end{bmatrix} * \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} Ax & Ay & Az \\ Bx & By & Bz \\ Cx & Cy & Cz \end{bmatrix} * \begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix}$$

The ship's X unit vector (1,0,0), the vector which, according to the ship is straight ahead, transforms to (Ax,Bx,Cx). Thus the position of the ship in terms of the Universe's coordinates can be determined.

The complete transformation for the Ship to look at the Universe, taking into account the position of the Ship:

For X,Y,Z in Universe reference and X', Y', Z' in Ship's reference

TO211X

$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = \begin{bmatrix} Ax & Bx & Cx \\ Ay & By & Cy \\ Az & Bz & Cz \end{bmatrix} * \begin{bmatrix} X-XT \\ Y-YT \\ Z-ZT \end{bmatrix}$$

INDEPENDENT OBJECTS

To draw objects in a polygon-based system, rotating the vertices that define the polygon will rotate the polygon.

The object will be defined in its own coordinate system (the object "library") and have associated with it a set of unit vectors. The object is rotated by rotating its unit vectors. The object will also have a position in the absolute Universe.

When we want to look at an object from any frame of reference we will transform each point in the object's library by applying a rotation matrix to place the object in the proper orientation. We will then apply a translation vector to place the object in the proper position. The rotation matrix is derived from both the object's and the observer's unit vectors; the translation vector is derived from the object's position, the observer's position, and the observer's unit vectors.

The simplest frame of reference from which to view an object is in the Universe's reference at (0,0,0) looking along the X axis. The reason is that we already have the rotation coeficients to look at the object. The object's unit vectors supply the matrix coefficients for the object to look at (rotate) the Universe. The inverse of this matrix will allow the Universe to look at (rotate) the object. As discussed previously, the unit vectors form an Orthonormal matrix; its inverse is simply the Transpose. After the object is rotated, it is translated to its position (its position according to the Universe) and projected. More on projection later.

A consequence of using the Unit Vector method is that, whatever orientation the object is in, it will always Roll, Pitch, and Yaw according to ITS axes.

For an object with unit vectors:

T0230X

$$\begin{bmatrix} Ax & Bx & Cx \\ Ay & By & Cy \\ Az & Bz & Cz \end{bmatrix}$$

and absolute position [XT,YT,ZT], and [X,Y,Z] a point from the object's library, and [X',Y',Z'] in the Universe's reference,

The Universe looks at the object:

T0231X

$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = \begin{bmatrix} Ax & Ay & Az \\ Bx & By & Bz \\ Cx & Cy & Cz \end{bmatrix} * \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} XT \\ YT \\ ZT \end{bmatrix}$$

For two ships, each with unit vectors and positions:

T0232X

$$\begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix}$$ Ship 1 Unit Vectors

(XT1,YT1,ZT1) Ship 1 Position

$$\begin{bmatrix} Ax2 & Bx2 & Cx2 \\ Ay2 & By2 & Cy2 \\ Az2 & Bz2 & Cz2 \end{bmatrix}$$ Ship 2 Unit Vectors

(XT2,YT2,ZT2) Ship 2 Position

$$\begin{bmatrix} Ax2 & Ay2 & Az2 \\ Bx2 & By2 & Bz2 \\ Cx2 & Cy2 & Cz2 \end{bmatrix}$$ Transpose (Inverse) of Ship 2 Unit Vectors

(X,Y,Z) in Ship 2 library, (X',Y',Z') in Universe Reference, and (X",Y",Z") in Ship 1 Reference

Universe looks at ship 2:

T0233X

$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = \begin{bmatrix} Ax2 & Ay2 & Az2 \\ Bx2 & By2 & Bz2 \\ Cx2 & Cy2 & Cz2 \end{bmatrix} * \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} XT2 \\ YT2 \\ ZT2 \end{bmatrix}$$

Ship 1 looks at the Universe looking at Ship 2:

T0234X

$$\begin{bmatrix} X'' \\ Y'' \\ Z'' \end{bmatrix} = \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} X' - XT1 \\ Y' - YT1 \\ Z' - ZT1 \end{bmatrix}$$

$$= \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} - \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} XT1 \\ YT1 \\ ZT1 \end{bmatrix} \qquad \text{EQUATION 10}$$

Expand:

T0240X

$$\begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \left(\begin{bmatrix} Ax2 & Ay2 & Az2 \\ Bx2 & By2 & Bz2 \\ Cx2 & Cy2 & Cz2 \end{bmatrix} * \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} XT2 \\ YT2 \\ ZT2 \end{bmatrix} \right)$$

Using the Distributive Law of Matrices:

T0241X

$$= \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \left(\begin{bmatrix} Ax2 & Ay2 & Az2 \\ Bx2 & By2 & Bz2 \\ Cx2 & Cy2 & Cz2 \end{bmatrix} * \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \right) + \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} XT2 \\ YT2 \\ ZT2 \end{bmatrix}$$

Using the Associative Law of Matrices:

T0242X

$$= \left(\begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} Ax2 & Ay2 & Az2 \\ Bx2 & By2 & Bz2 \\ Cx2 & Cy2 & Cz2 \end{bmatrix} \right) * \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} XT2 \\ YT2 \\ ZT2 \end{bmatrix}$$

Substituting back into Equation 10 gives:

T0243X

$$\begin{bmatrix} X'' \\ Y'' \\ Z'' \end{bmatrix} = \left(\begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} Ax2 & Ay2 & Az2 \\ Bx2 & By2 & Bz2 \\ Cx2 & Cy2 & Cz2 \end{bmatrix} \right) * \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} XT2 \\ YT2 \\ ZT2 \end{bmatrix} - \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} XT1 \\ YT1 \\ ZT1 \end{bmatrix}$$

Therefore:

T0244X

$$\begin{bmatrix} X'' \\ Y'' \\ Z'' \end{bmatrix} = \left(\begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} AX2 & Ay2 & Az2 \\ Bx2 & By2 & Bz2 \\ CX2 & Cy2 & Cz2 \end{bmatrix} \right) * \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} XT2-XT1 \\ YT2-YT1 \\ ZT2-ZT1 \end{bmatrix}$$

EQUATION 11

Now let:

T0245X

$$\begin{bmatrix} Ax & Bx & Cx \\ Ay & By & Cy \\ Az & Bz & Cz \end{bmatrix} = \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} Ax2 & Ay2 & Az2 \\ Bx2 & By2 & Bz2 \\ Cx2 & Cy2 & Cz2 \end{bmatrix}$$

EQUATION 12

This matrix represents the orientation of Ship 2 according to Ship 1's frame of reference. This concatentation needs to be done only once per update of Ship 2.

Also let:

T0250X

$$\begin{bmatrix} XT \\ YT \\ ZT \end{bmatrix} = \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} XT2-XT1 \\ YT2-YT1 \\ ZT2-ZT1 \end{bmatrix} \qquad \text{EQUATION 13}$$

(XT,YT,ZT) is merely the position of Ship 2 in Ship 1's frame of reference.

This also needs to be done only once per update of Ship 2. Therefore the transformation to be applied to Ship 2's library will be of the form:

T0251X

$$\begin{bmatrix} X'' \\ Y'' \\ Z'' \end{bmatrix} = \begin{bmatrix} Ax & Bx & Cx \\ Ay & By & Cy \\ Az & Bz & Cz \end{bmatrix} * \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} XT \\ YT \\ ZT \end{bmatrix} \qquad \text{EQUATION 14}$$

Therefore, every object has six degrees of freedom, and any object may look at any other object.

T0252X

SUMMARY OF TRANSFORMATION ALGORITHMS:

```
Define Unit Vectors:  [Px] = (Ax,Ay,Az)

                      [Py] = (Bx,By,Bz)

                      [Pz] = (Cx,Cy,Cz)

Initialize: Ax=By=Cz=1.000
            Ay=Az=Bx=Bz=Cx=Cy=0

If Roll:
        Ay' = Ay*COS(xa) - Az*SIN(xa)
        Az' = Ay*SIN(xa) + Az*COS(xa)

        By' = By*COS(xa) - Bz*SIN(xa)
        Bz' = By*SIN(xa) + Bz*COS(xa)

        Cy' = Cy*COS(xa) - Cz*SIN(xa)
        Cz' = Cy*SIN(xa) + Cz*COS(xa)

If Pitch:

        Az' = Az*COS(ya) - Ax*SIN(ya)
        Ax' = Az*SIN(ya) + Ax*COS(ya)

        Bz' = Bz*COS(ya) - Bx*SIN(ya)
        Bx' = Bz*SIN(ya) + Bx*SIN(ya)

        Cz' = Cz*COS(ya) - Cx*SIN(ya)
        Cx' = Cz*SIN(ya) + Cx*COS(ya)
```

If Yaw:

$$Ax' = Ax*COS(za) - Ay*SIN(za)$$
$$Ay' = Ax*SIN(za) + Ay*COS(za)$$

$$Bx' = Bx*COS(za) - By*SIN(za)$$
$$By' = Bx*SIN(za) + By*COS(za)$$

$$Cx' = Cx*COS(za) - Cy*SIN(za)$$
$$Cy' = Cx*SIN(za) + Cy*COS(za)$$

('za', 'ya', and 'xa' are incremental rotations.)

The resultant unit vectors form a transformation matrix. For X, Y, Z in Universe reference and X', Y', Z' in Ship's reference

$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = \begin{bmatrix} Ax & Bx & Cx \\ Ay & By & Cy \\ Az & Bz & Cz \end{bmatrix} * \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

and

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} Ax & Ay & Az \\ Bx & By & Bz \\ Cx & Cy & Cz \end{bmatrix} * \begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix}$$

The ship's x unit vector, the vector which according to the ship is straight ahead, transforms to (Ax,Bx,Cx). For a ship in free space, this is the acceleration vector when there is forward thrust. The sum of the accelerations determine the velocity vector and the sum of the velocity vectors determine the position vector (XT,YT,ZT).

For two ships, each with unit vectors and positions:

$$\begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix}$$ Ship 1 Unit Vectors

(XT1,YT1,ZT1) Ship 1 Position

$$\begin{bmatrix} Ax2 & Bx2 & Cx2 \\ Ay2 & By2 & Cy2 \\ Az2 & Bz2 & Cz2 \end{bmatrix}$$ Ship 2 Unit Vectors

(XT2,YT2,ZT2) Ship 2 Position

Ship 1 looks at the Universe:

T0270X

$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} X-XT \\ Y-YT \\ Z-ZT \end{bmatrix}$$

(X,Y,Z) in Universe
(X',Y',Z') in Ship 1 frame of reference

Ship 1 looks at Ship 2:

$$\begin{bmatrix} Ax & Bx & Cx \\ Ay & By & Cy \\ Az & Bz & Cz \end{bmatrix} = \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} Ax2 & Ay2 & Az2 \\ Bx2 & By2 & Cy2 \\ Cx2 & Cy2 & Cz2 \end{bmatrix}$$

(Ship 2 orientation relative to Ship 1 orientation)

T0271X

$$\begin{bmatrix} XT \\ YT \\ ZT \end{bmatrix} = \begin{bmatrix} Ax1 & Bx1 & Cx1 \\ Ay1 & By1 & Cy1 \\ Az1 & Bz1 & Cz1 \end{bmatrix} * \begin{bmatrix} XT2-XT1 \\ YT2-YT1 \\ ZT2-ZT1 \end{bmatrix}$$

(Ship 2 position in Ship 1's frame of reference)

$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = \begin{bmatrix} Ax & Bx & Cx \\ Ay & By & Cy \\ Az & Bz & Cz \end{bmatrix} * \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} + \begin{bmatrix} XT \\ YT \\ ZT \end{bmatrix}$$

(X,Y,Z) in Ship 2 library
(X',Y',Z') in Ship 1 reference

VISIBILITY AND ILLUMINATION

After a polygon is transformed, whether it is a terrain polygon or it belongs to an independently moving object such as another aircraft, the next step is to determine its illumination value, if indeed, it is visible at all.

Associated with each polygon is a vector of length 1 that is normal to the surface of the polygon. This is obtained by using the vector crossproduct between the vectors forming any two adjacent sides of the polygon. For two vectors V1 = [x1,y1,z1] and V2 = [x2,y2,z2] the crossproduct V1 X V2 is the vector [(y1*z2-y2*z1),-(x1*z2-x2*z1),(x1*y2-x2*y1)]. The vector is then normalized by dividing it by its length. This gives it a length of 1. This calculation can be done when the data base is generated, becoming part of the data base, or it can be done during program run time. The tradeoff is between data base size and program execution time. In any event, it becomes part of the transformed data.

After the polygon and its normal are transformed to the aircraft's frame of reference, we need to calculate the angle between the polygon's normal and the vector from the base of the normal to the aircraft. This is done by taking the vector dot product. For two vectors V1 = [x1,y1,z1] and V2 = [x2,y2,z2], V1 dot V2 = length(V1) * length(V2) * cos(a) and is calulated as (x1*x2 + y1*y2 + z1*z2). Therefore:

Ta230

$$\cos(a) = \frac{(x1*x2 + y1*y2 + z1*z2)}{length(V1) * length(V2)}$$

A cosine that is negative means that the angle is between 90 degress and 270 degrees. Since this angle is facing away from the observer it will not be visible and can be rejected and not subjected to further processing. The actual cosine value can be used to determine the brightness of the polygon for added realism.

CLIPPING

Now that the polygon has been transformed and checked for visibility it must be clipped so that it will properly fit on the screen after it is projected. Standard clipping routines are well known in the computer graphics industry. There are six clipping planes as shown in the 3D representation shown in FIG. 8a . The 2D top view is shown in FIG. 8b, and the 2D side view is shown in FIG. 8c. It should be noted that clipping a polygon may result in the creation of addition polygon sides which must be added to the polygon description sent to the polygon display routine.

PROJECTION

As shown in FIG. 7a, X' is the distance to the point along the X axis, Z' is the height of the point, Xs is the distance from the eyepoint to the screen onto which the point is to be projected, and Sy is the vertical displacement on the screen. Z'/X' and Sy/Xs form similar triangles so: Z'/X' = Sy/Xs , therefore Sy = Xs*Z'/X' . Likewise, Y'/X' = Sx/Xs so Sx = Xs*Y'/X' where Sx is the horizontal displacement on the screen. However, we still need to fit Sy and Sx to the monitor display coordinates. Suppose we have a screen that is 1024 by 1024. Each axis would be plus or minus 512 with (0,0) in the center. If we want a 90 degree field of view (plus or minus 45 degrees from the center), then when a point has Z'/X'=1 it must be put at the edge of the screen where its value is 512. Therefore Sy = 512*Z'/X'. (Sy is the Screen Y-coordinate).

Therefore:

Sy = K*Z'/X'	Sy is the vertical coordinate on the display
Sx = K*Y'/X'	Sx is the horizontal coordinate on the display

K is chosen to make the viewing angle fit the monitor coordinates. If K is varied dynamically we end up with a zoom lens effect. And if we are clever in implementing the divider, K can be performed without having to actually do a multiplication.

THE DATABASE

The data base is generated from several sources. The U.S. Geological ~~Service~~ Survey (USGS) makes available various databases, two of which are of particular interest. The first is the Digital Elevation Model data which consist of an array of regularly spaced terrain elevations. This data base is converted into a data base containing polygons (whose vertices are three-dimensional points) in order to maximize the geographic area covered by CD-ROM Data Base 105 and also to reduce the amount of run-time processing required of Computer 107. This is possible because there are large areas of terrain that are essentially flat. Note that flat does not necessarily mean level. A sloping area is flat without being level.

The Digital Elevation Model data elevations are spaced 30 meters apart. 30 meters = 30m x 39.37in/m x 1ft/12 in = 98.245 ft . A linear mile contains 5,280 ft/mi x 1 data point/98.245 ft = 53.65 data points/mi . Therefore, a square mile contains 53.65 x 53.65 = 2878 data points. California has a total area of 158,706 square miles which requires 158,706 x 2878 = 456,755,868 data points. Since this figure includes 2,407 sq mi of inland water areas, there are 2407 x 2878 = 6,927,346 data points just for inland water. The U.S. has a total area of 3,618,773 square miles which requires 3,618,773 x 2878 = 10,414,828,694 data points. This figure includes 79,484 sq mi of inland water areas requiring 79,484 x 2878 = 228,754,952 data points just for inland water.

The polygon data are organized in geographic data blocks. Because the amount of data in each geographic data block depends on the number of polygons and because the number of polygons depends on the flatness of the terrain, the size of each geographic data block is variable. Therefore, an address table is maintained that contains a pointer to each geographic data block. The first choice is to decide on the geographic area represented by the block. For the present invention the size is 20 mi x 20 mi = 400 sq mi . Therefore, the polygon data base for California requires 158,706 sq mi x 1 block/400 sq mi = 397 geographic data blocks. The number of polygons in a given geographic data block depends on the flatness of the terrain and what we decide is 'flat'. The definition of 'flatness' is that for a polygon whose vertices are three-dimensional points, there will be no elevation points that are higher than the plane of the polygon and there will be no elevation points that are below the the plane of the polygon by a distance called the Error Factor. A small Error Factor will require more polygons to represent a given terrain than will a large Error Factor. A small Error Factor will also generate the terrain more accurately. The Error Factor does not have to be the same for all Geographic Data Blocks. Blocks for areas of high interest, like airports and surrounding areas can be generated using a small Error Factor in order to represent the terrain more precisely. The present invention uses an Error Factor of 10 ft for areas surrounding airports and 50 ft for all other areas.

A procedure for generating the polygon data base from the Digital Elevation Model data is demonstrated in FIG. 12a through FIG. 12f and FIG. 13a through FIG. 13f. We start with three points which define a polygon and which has a surface. We select the next elevation point and decide if it belongs in the polygon accordinng to the citeria previously discussed. If it does, it gets added to the polygon. If not, not. We then test additional adjacent points until we run out. Then we start over with another three points.

When we are done generating polygons for a Geographic Data Block we go back and examine them; any polygon that is 'too big' is broken down into smaller polygons. This is to make sure there are always enough polygons on the screen to provide a proper reference for the pilot. (A single large polygon on the screen would not have any apparent motion.) Finally, the polygons are assigned colors and/or shades so that adjacent polygons will not blend into each other.

The other USGS data base used is the Digital Line Graph data which includes: political and administrative boundaries; hydrography consisting of all flowing water, standing water, and wetlands; major transportation systems consisting of roads and trails, railroads, pipelines, transmission lines, and airports; and significant manmade structures. The Digital Line Graph data is two-dimensional. In the present invention features such as water, roads, railroads, and pipelines are represented as polygons with elevations determined from the Digital Elevation Model data. Transmission lines and significant manmade structures are defined as three-dimensional objects made of polygons and are placed according to the elevations determined from the Digital Elevation Model data. The different types of objects are tagged so that by using Control Panel 106 the pilot can select them to be highlighted by category or by specific object. For example, the pilot can choose to have all airports highlighted or just the destination airport. The pilot can also choose to have a specific highway highlighted.

Data from additional digital data bases can also be incorporated. An example of such a data base is from Jeppesen Sanderson whose NavData Services division provides aeronautical charts and makes this information available in digital form.

While preferred embodiments of the present invention have been shown, it is to be expressly understood that modifications and changes may be made thereto and that the present invention is set forth in the following claims.

I claim:

Sub A1

1. A pilot aid which uses an aircraft's position and attitude to transform data from a digital data base to present a pilot with a synthesized three dimensional projected view of the world comprising:

a position determining means for locating said aircraft's position in three dimensions;

a digital data base means containing polygon data representing terrain and manmade structures;

an attitude determining means for determining said aircraft's orientation in three dimensional space;

a control panel means for allowing said pilot to select different operating features;

a computer means for using said aircraft position data to access said terrain and manmade structure data from said digital data base and using said aircraft orientation data to transform said terrain and manmade structure data to provide three dimensional projected image data according to said operating features selected by said pilot;

a display means for displaying said three dimensional projected image data.

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2. The position determining means of claim 1, wherein said position determining means comprises a standard system for receiving and processing data from the global positioning system.

3. The attitude determining means of claim 1, wherein said attitude determining means comprises a standard avionics system.

4. The digital data base of claim 1, wherein said digital data base means comprises a cd rom disc and cd rom drive.

5. The control panel means of claim 1, wherein said control panel means selects the functions of pan, tilt, and zoom.

6. The control panel means of claim 1, wherein said control panel means permits said pilot to preview the route ahead.

7. A pilot aid which uses an aircraft's position and attitude to transform data from a digital data base to present a pilot with a synthesized three dimensional projected view of the world comprising:

a position determining means for locating said aircraft's position in three dimensions;

a digital data base means containing polygon data representing terrain and manmade structures;

an attitude determining means for determining said aircraft's orientation in three dimensional space;

a control panel means for allowing said pilot to select different operating features;

a computer means for using said aircraft position data to access said terrain and manmade structure data from said digital data base and using said aircraft orientation data to transform said terrain and manmade structure data to provide three dimensional projected image data according to said operating features selected by said pilot;

a display means for displaying said three dimensional projected image data;

a mass storage memory for recording said aircraft position data and said aircraft's attitude data for allowing said aircraft's flight to be displayed at a later time.

8. The position determining means of claim 7, wherein said position determining means comprises a standard system for receiving and processing data from the global positioning system.

9. The attitude determining means of claim 7, wherein said attitude determining means comprises a standard avionics system.

10. The digital data base of claim 7, wherein said digital data base means comprises a cd rom and cd rom drive.

11. The control panel means of claim 7, wherein said control panel means selects the functions of pan, tilt, and zoom.

12. The control panel means of claim 7, wherein said control panel means permits said pilot to preview the route ahead or to review previous flights.

13. A pilot aid which uses an aircraft's position and attitude to transform data from a digital data base to present a pilot with a synthesized three dimensional projected view of the world comprising:

a position determining means for locating said aircraft's position in three dimensions;

a digital data base means containing polygon data representing terrain and manmade structures;

an attitude determining means for determining said aircraft's orientation in three dimensional space;

a head mounted display means worn by said pilot of said aircraft;

an attitude determining means for determining the orientation of said pilot's head in three dimensional space;

a control panel means for allowing said pilot to select different operating features;

a computer means for using said aircraft position data to access said terrain and manmade structure data from said digital data base and using said aircraft orientation data and said pilot head orientation data to transform said terrain and manmade structure data to provide three dimensional projected image data to said head mounted display according to said operating features selected by said pilot.

add a1

Declaration for Utility or Design Patent Application

As a below-named inventor, I hereby declare that my residence, post office address, and citizenship are as stated below next to my name and that I believe that I am the original, first, and sole inventor [if only one name is listed below] or an original, first, and joint inventor [if plural names are listed below] of the subject matter which is claimed and for which a patent is sought on the invention, the specification of which is attached hereto and which has the following title:

" PILOT AID USING SYNTHETIC REALITY "

I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment specifically referred to in the oath or declaration. I acknowledge a duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, Section 1.56(a).

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, unter Title 18, United States Code, Section 1001, and that such willful false statements may jeopardize the validity of the application or any patent issues thereon.

Please send correspondance and make telephone calls to the First Inventor below.

Signature: Sole/First Inventor Jed Margolin

Print Name: Jed Margolin 1-00 C   Date: 10 July 1994

Residence: San Jose, CA   Citizen of: USA

Post Office Address: 3570 Pleasant Echo Dr.

San Jose, CA 95148-1916 CA

Telephone: (408) 238-4564

Signature: Joint/Second Inventor ______

Print Name: ______   Date: ______

Residence: ______   Citizen of: ______

Post Office Address: ______

______

Telephone: ______

In the United States Patent and Trademark Office

First/Sole Applicant: Jed Margolin

Joint/Second Applicant: ______

Title: " PILOT AID USING SYNTHETIC REALITY "

Small Entity Declaration - Independent Inventor(s)

As a below-named inventor, I hereby declare that I quality as an independent inventor as defined in 37 CFR 1.9(c) for the purposes of paying reduced fees under Section 41(a) and (b) of Title 35 United States Code, to the Patent and Trademark Office with regard to my above-identified invention described in the specification filed herewith. I have not assigned, granted, conveyed, or licensed - and am under no obligation under any contract or law to assign, grant, convey, or license - any rights in the invention to either (a) any person who could not be classified as an independent inventor under 37 CFR 1.9(c) if that person had made the invention or (b) any concern which would not qualify as either (i) a small business concern under 37 CFR 1.9(d) or (ii) a nonprofit organization under 37 CFR 1.9(e).

Each person, concern, or organization to which I have assigned, granted, conveyed, or licensed - or am under an obligation under contract or law to assign, grant, convey, or license - any rights in the invention is listed below:

[✓] There is no such person, concern, or organization.

[ ] Any applicable person, concern, or organization is listed below:

Full Name: ______

Address: ______

I acknowledge a duty to file, in the above application for patent, notification of any change in status resulting in loss of entitlement to small entity status prior to paying, or at the time of paying, the earliest of the issue fee or any maintenance fee due after the date on which status as a small entity is no longer appropriate. (37 CFR 1.28(b).

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application, any patent issuing thereon, or any patent to which this verified statement is directed.

Jed Margolin
Signature of Sole/First Inventor

Jed Margolin
Print Name of Sole/First Inventor

Date of Signature: 10 July 1994

______
Signature of Joint/Second Inventor

______
Print Name of Joint/Second Inventor

Date of Signature: ______

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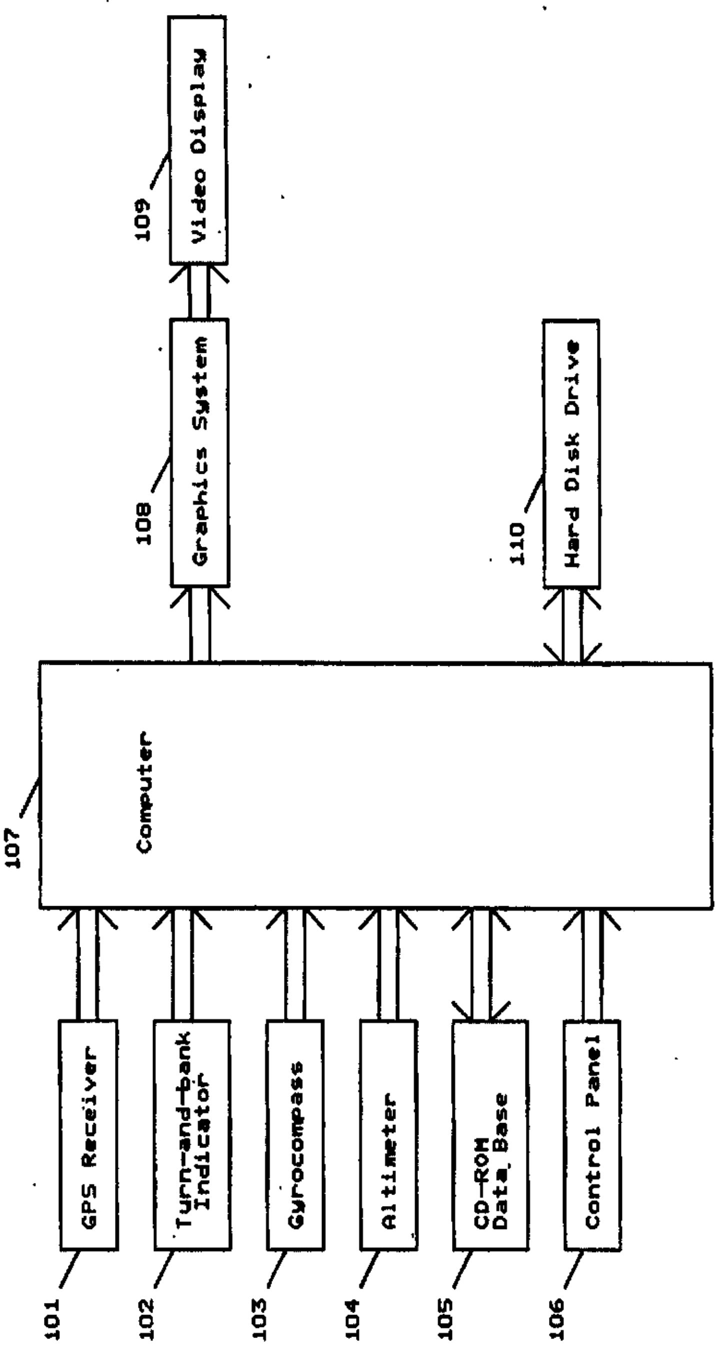

109
Video Display
108
Graphics System
110
Hard Disk Drive
107
Computer
101
GPS Receiver
102
Turn-and-bank Indicator
103
Gyrocompass
104
Altimeter
105
CD-ROM Data Base
106
Control Panel

Fig. 1

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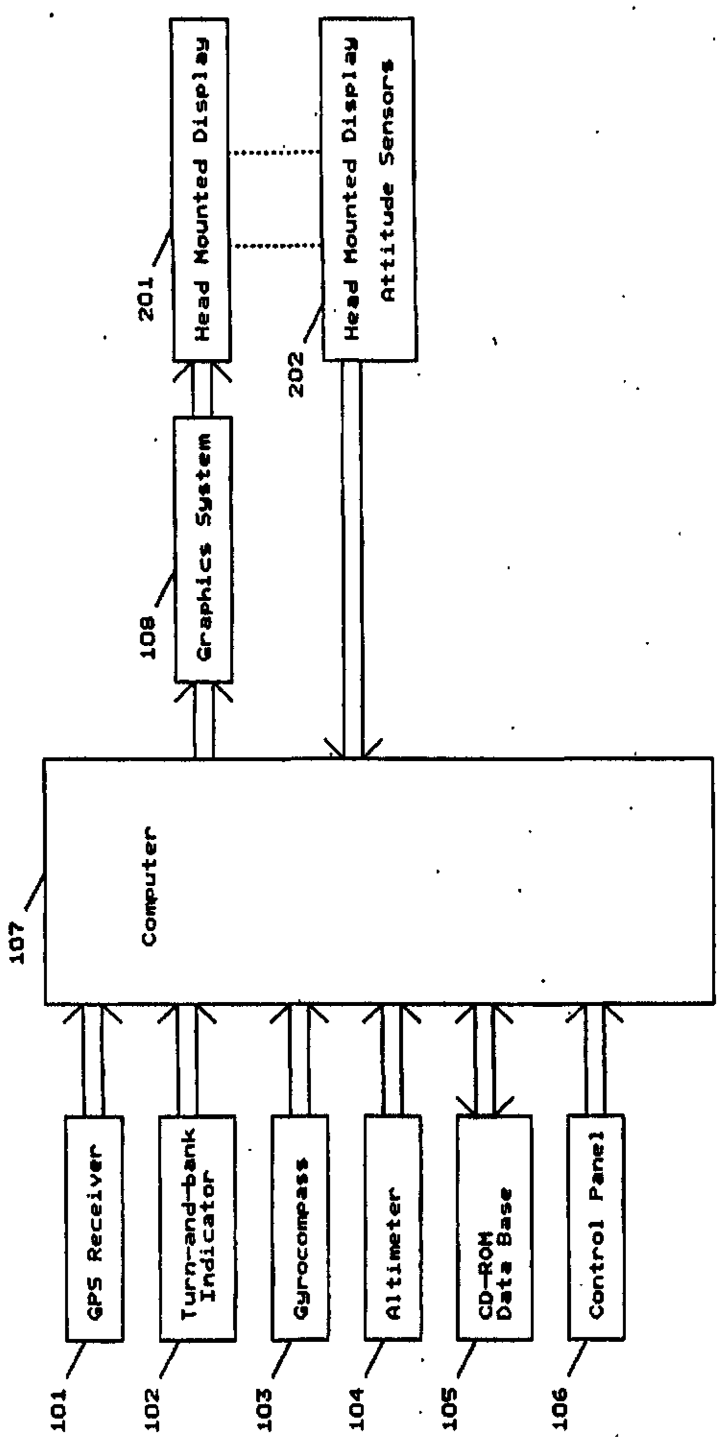
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107
Computer
101
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Turn-and-bank
Indicator
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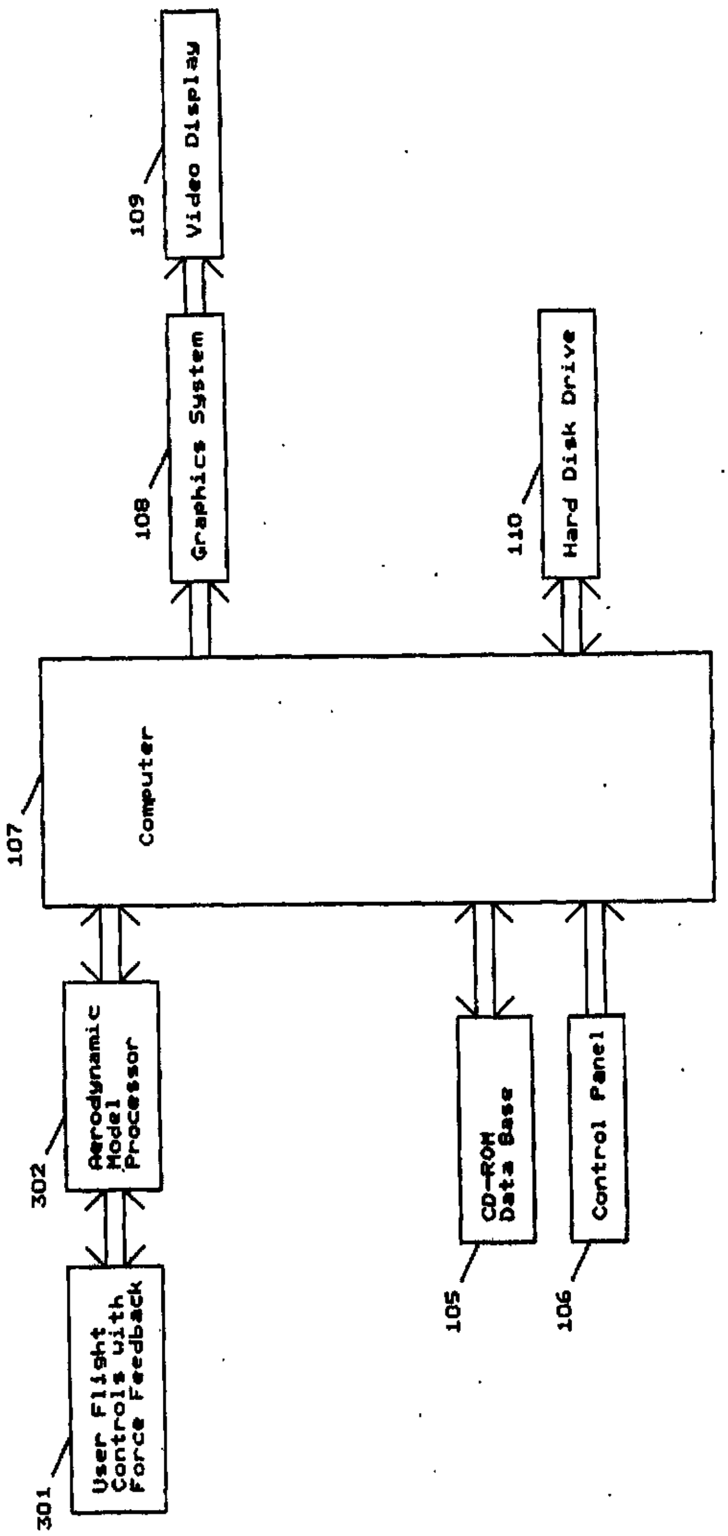
Gyrocompass
104
Altimeter
105
CD-ROM
Data Base
106
Control Panel

Fig. 2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Video Display
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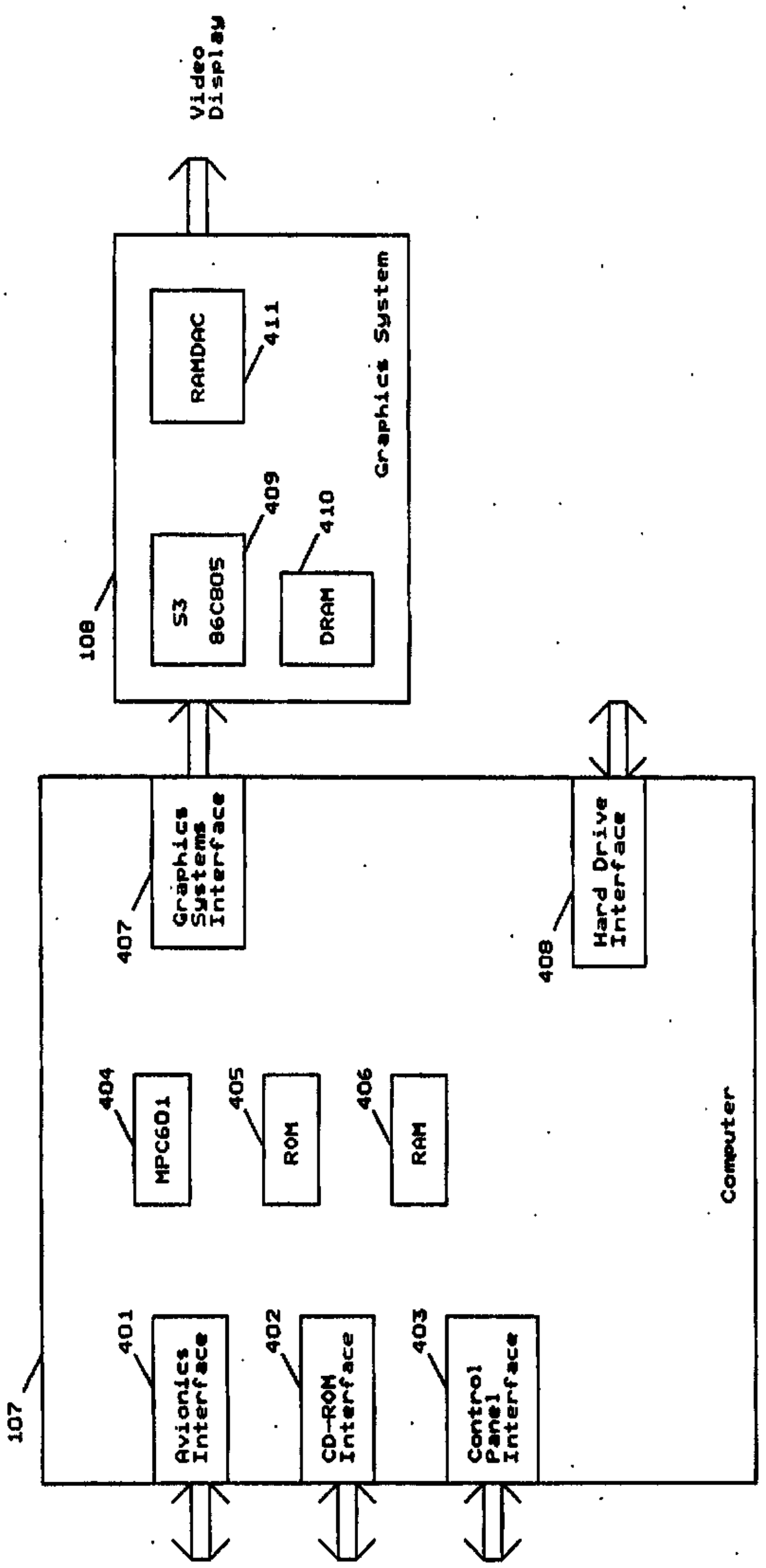
Graphics System
110
Hard Disk Drive
107
Computer
302
Aerodynamic Model Processor
301
User Flight Controls with Force Feedback
105
CD-ROM Data Base
106
Control Panel

Fig. 3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RAMDAC
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S3
86C805
409
DRAM
410
108
Graphics Systems Interface
407
Hard Drive Interface
408
MPC601
404
ROM
405
RAM
406
Computer
Avionics Interface
401
CD-ROM Interface
402
Control Panel Interface
403
107

Fig. 4

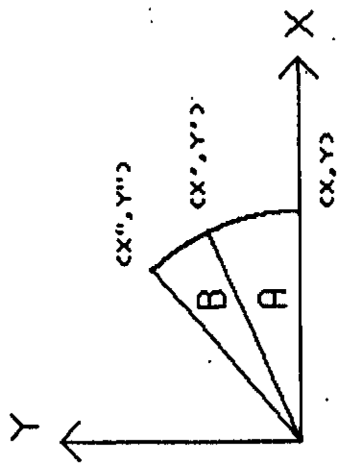

Fig. 5b

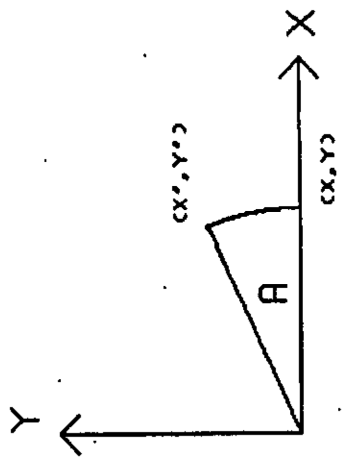

Fig. 5a

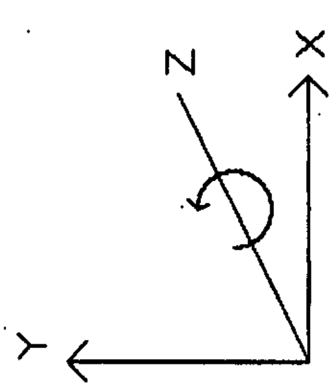

Fig. 6a

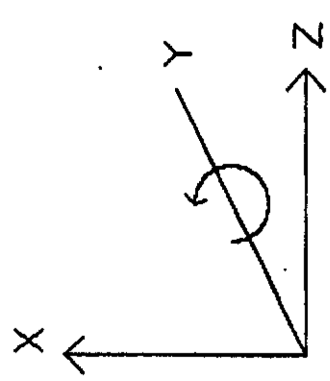

Fig. 6b

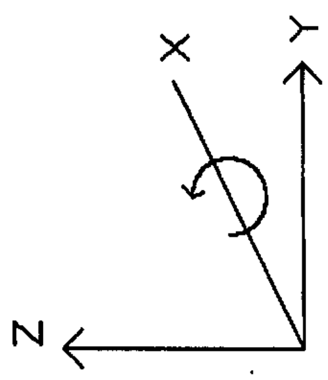

Fig. 6c

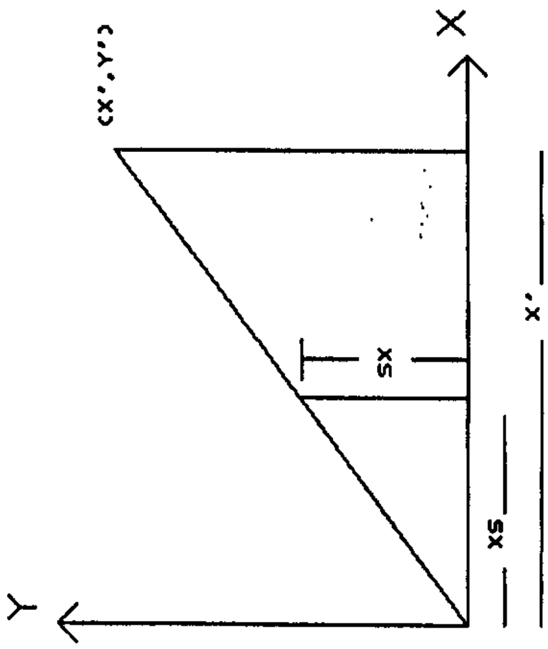

Fig. 7b Top

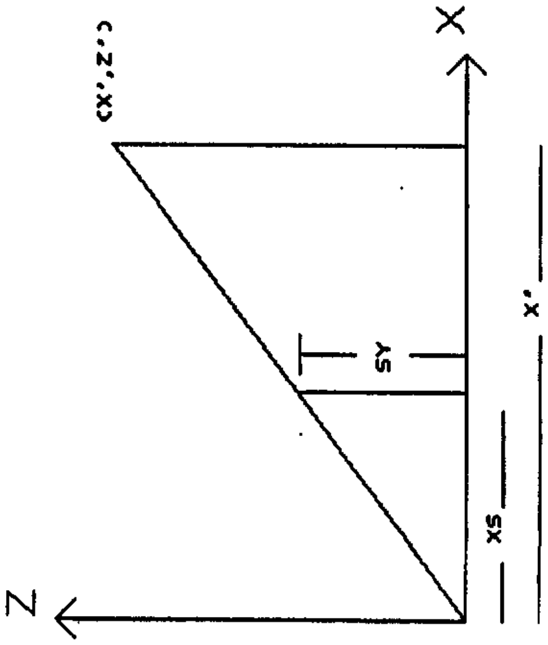

Fig. 7a Side

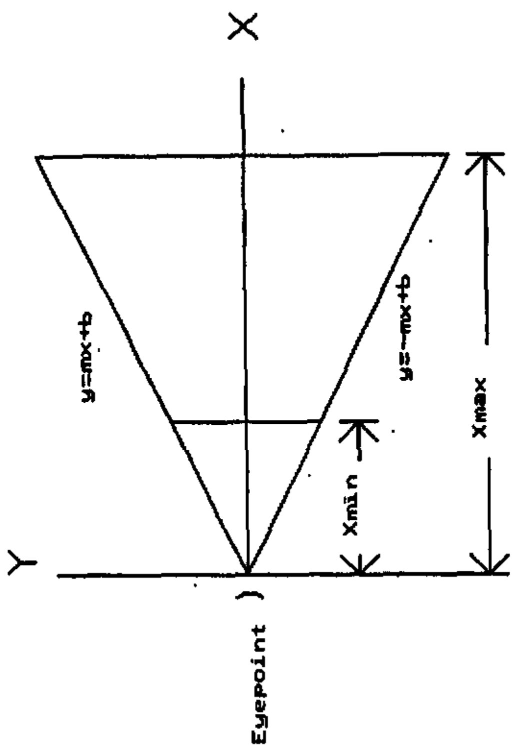

Fig. 8b Top View

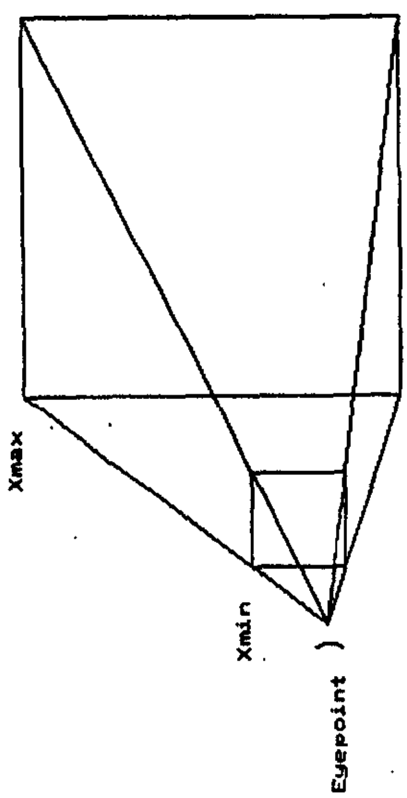

Fig. 8a

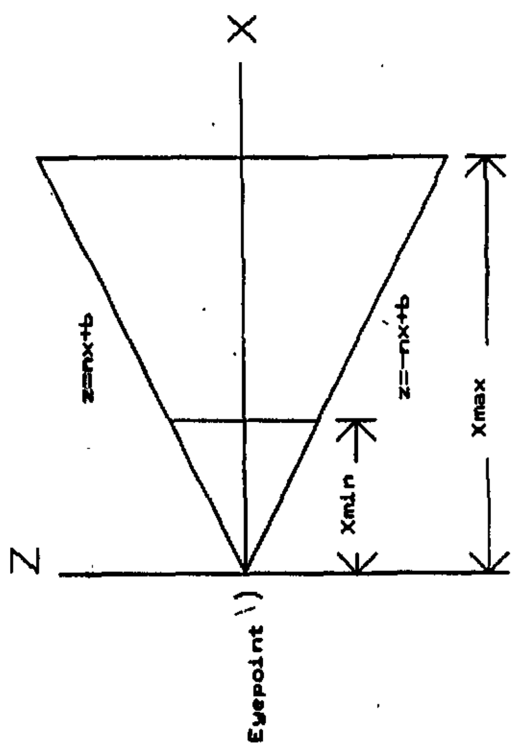

Fig. 8c Side View

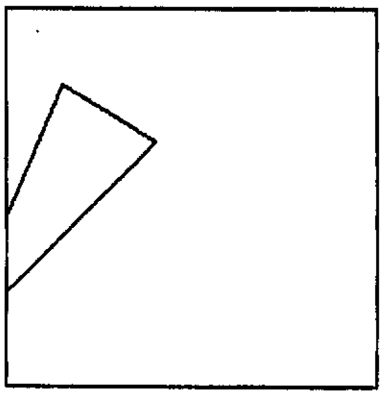

Fig. 9b

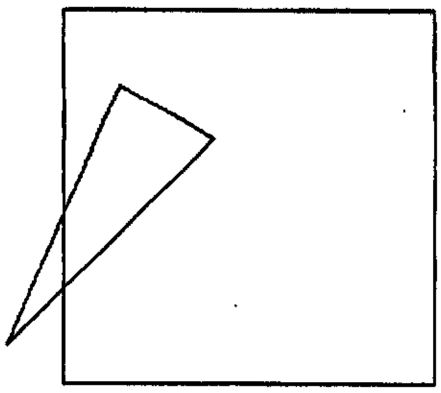

Fig. 9a

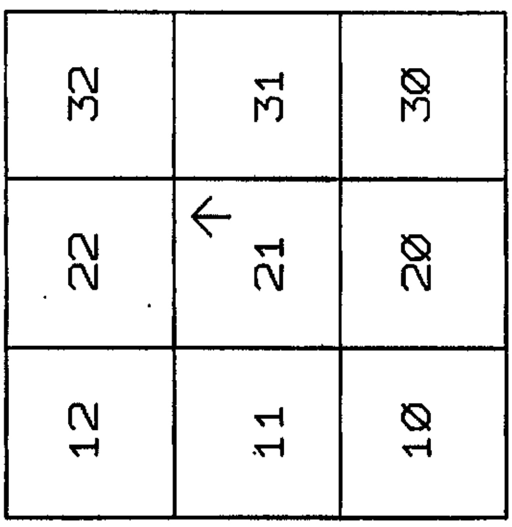

Fig. 1Øa

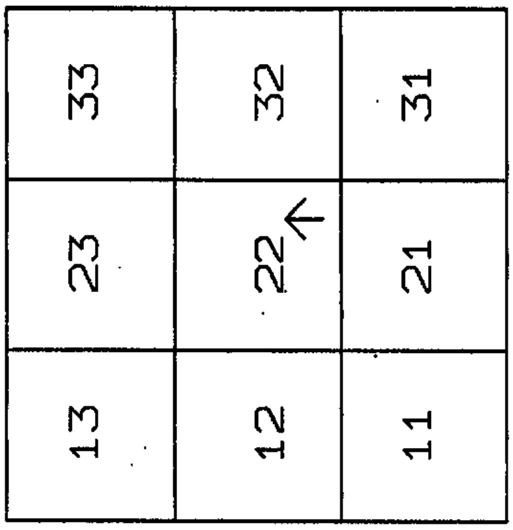

Fig. 1Øb

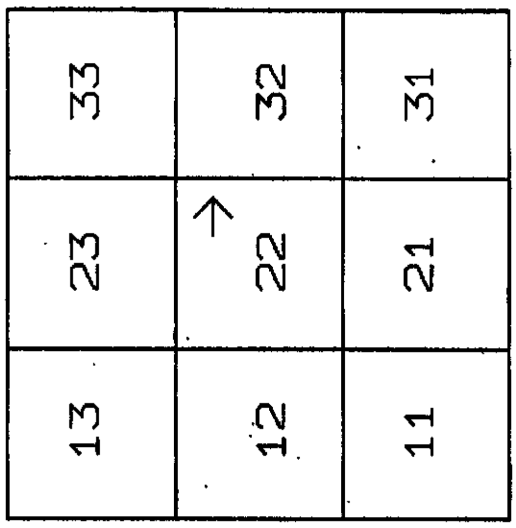

Fig. 11a

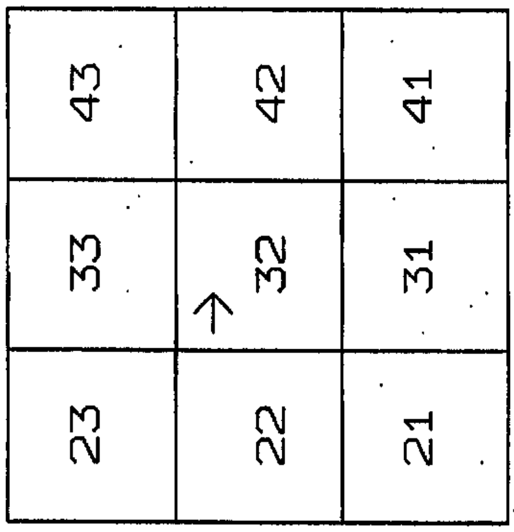

Fig. 11b

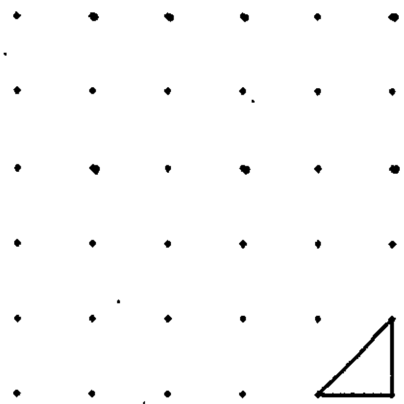

Fig. 12a

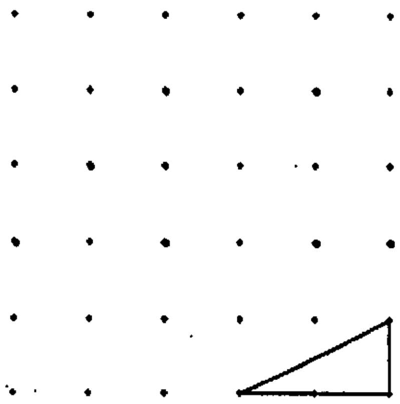

Fig. 12b

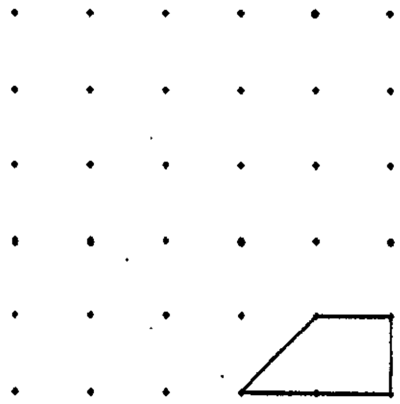

Fig. 12c

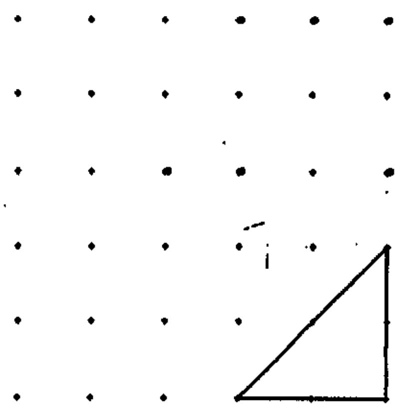

Fig. 12d

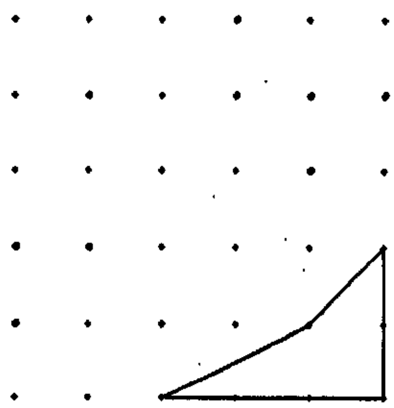

Fig. 12e

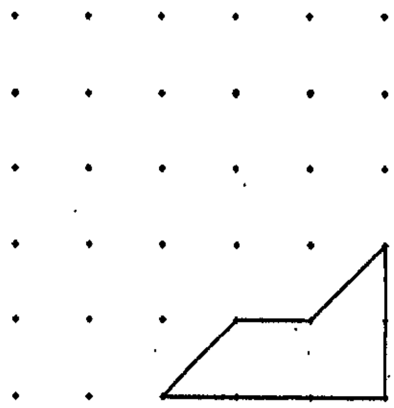

Fig. 12e

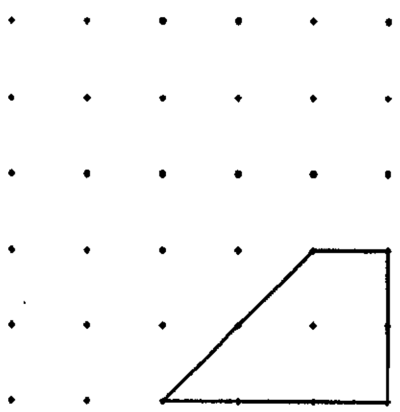

Fig. 13a

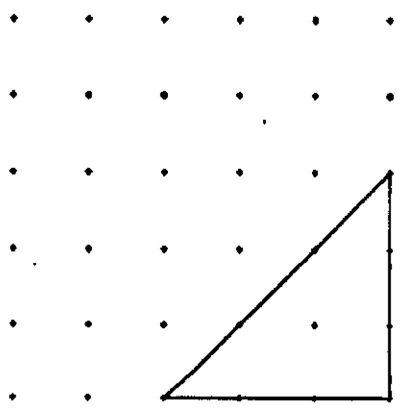

Fig. 13b

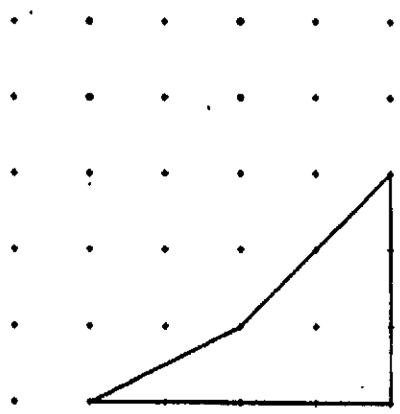

Fig. 13c

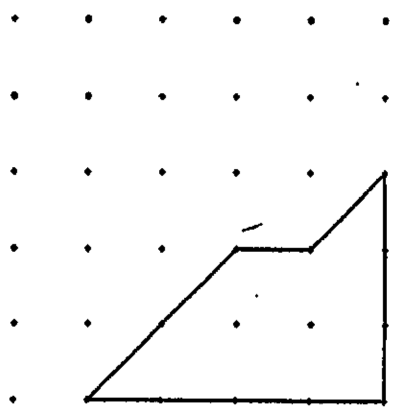

Fig. 13d

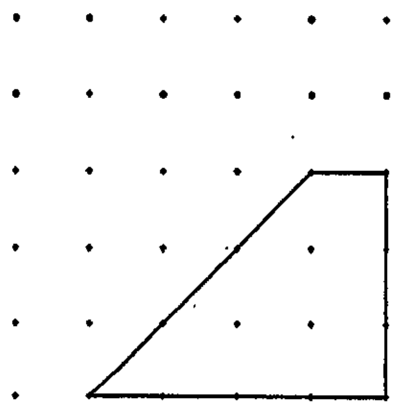

Fig. 13e

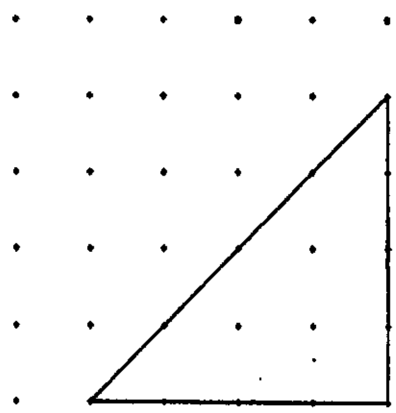

Fig. 13e

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274394

In the United States Patent and Trademark Office

Mailed 11 July 1994

Commissioner of Patents and Trademarks
Washington, District of Columbia 20231

Sir:

Please file the following enclosed patent application papers:

Applicant #1, Name: Jed Margolin

Applicant #2, Name:

Title: PILOT AID USING SYNTHETIC REALITY

[✓] Specification, Claims, and Abstract: Nr. of Sheets 36

[✓] Declaration: Date Signed: 10 July 1994

[✓] Drawing(s): Nr. of Sheets Enc.:(In Triplicate): Formal: 13 Informal: ____

[✓] Small Entity Declaration of Inventor(s) [ ] SED of Non-Inventor/Assignment/Licensee

[ ] Assignment; please record and return; recordal fee enclosed.

Check for $ 355 for:

[✓] $ 355 for filing fee (not more than three independent claims and twenty total claims are presented).

[ ] $________ Additional if Assignment is enclosed for recordal.

[✓] Return Receipt Postcard Addressed to Applicant #1.

[✓] **Request Under MPEP § 707.07(j):** The undersigned, a pro-se applicant, respectfully requests that if the Examiner finds patentable subject matter disclosed in this application but feels that Applicant's present claims are not entirely suitable, the Examiner draft one or more allowable claims for applicant.

Very respectfully,

Jed Margolin

Applicant #1 Signature

Applicant #2 Signature

3570 Pleasant Echo Dr.

Address (Send Correspondence Here)

Address

San Jose, CA 95148-1916

Express Mail Label # EF981868779US ; **Date of Deposit** 11 July 1994

I hereby certify that this paper or fee is being deposited with the United States Postal Service using "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to "Commissioner of Patents and Trademarks, Washington, DC 20231."

Signed: Jed Margolin
Inventor

In the United States Patent and Trademark Office
Information Disclosure Statement

Commissioner of Patents and Trademarks
Washington, District of Columbia 20231

Sir:

Attached are completed Form PTO-1449 and copies of the pertinent parts of the references cited thereon. Following are comments on these references pursuant to Rule 98:

The 1984 patent to Taylor et al. (U.S. Patent No. 4,445,118) shows the basic operation of the global positioning system (GPS).

The 1984 patent to Johnson et al. (U.S. Patent No. 4,468,793) shows a receiver for receiving GPS signals.

The 1984 patent to Maher (U.S. Patent No. 4,485,383) shows another receiver for receiving GPS signals.

The 1986 patent to Evans (U.S. Patent No. 4,599,620) shows a method for determining the orientation of a moving object and producing roll, pitch, and yaw information.

The 1992 patent to Timothy et al. (U.S. Patent No. 5,101,356) also shows a method for determining the orientation of a moving object and producing roll, pitch, and yaw information.

The 1993 patent to Ward et al. (U.S. Patent No. 5,185,610) shows a method for determining the orientation of a moving object from a single GPS receiver and producing roll, pitch, and yaw information.

The 1992 patent to Fraughton et al. (U.S. Patent No. 5,153,836) shows a navigation, surveillance, emergency location, and collision avoidance system and method whereby each craft determines its own position using LORAN or GPS and transmits it on a radio channel along with the craft's identification information. Each craft also receives the radio channel and thereby can determine the position and identification of other craft in the vicinity.

The 1992 patent to Beckwith et al. (U.S. Patent No. 5,140,532) provides a topographical two-dimensional real-time display of the terrain over which the aircraft is passing, and a slope-shading technique incorporated into the system provides to the display an apparent three-dimensional effect similar to that provided by a relief map. This is accomplished by reading compressed terrain data from a cassette tape in a controlled manner based on the instantaneous geographical location of the aircraft as provided by the aircraft navigational computer system, reconstructing the compressed data by suitable processing and writing the reconstructed data into a scene memory with a north-up orientation. A read control circuit then controls the read-out of data from the scene memory with a heading-up orientation to provide a real-time display of the terrain over which the aircraft is passing. A symbol at the center of display position depicts the location of the aircraft with respect to the terrain, permitting the pilot to navigate the aircraft even under conditions of poor visibility. However, the display provided by this system is in the form of a moving map rather than a true perspective display of the terrain as it would appear to the pilot through the window of the aircraft.

The 1987 patent to Beckwith et al. (U.S. Patent No. 4,660,157) is similar to U.S. Patent No. 5,140,532. It also reads compressed terrain data from a cassette tape in a controlled manner based on the instantaneous geographical location of the aircraft as provided by the aircraft navigational computer system and reconstructs the compressed data by suitable processing and writing the reconstructed data into a scene memory. However, instead of providing a topographical two-dimensional display of the terrain over which the aircraft is passing and using a slope-shading technique to provide an apparent three-dimensional effect similar to that provided by a relief map as shown in the '532 patent, the '157 patent processes the data to provide a 3D perspective on the display. There are a number of differences between the '157 patent and the present invention:

1. The '157 Patent stores the map as a collection of terrain points with associated altitudes; the large amount of storage required by this approach requires that a tape be prepared for each mission.
   The present invention stores terrain data as a collection of polygons which results in a significant reduction of data base storage; larger geographic areas can be stored so that it it not necessary to generate a data base for each mission.
2. The '157 Patent uses a tape cassette for data base storage; the long access time for tape storage makes it necessary to use a relatively large cache memory. The present invention uses a CD-ROM which permits random access to the data so that the requirements for cache storage are reduced.
3. The '157 Patent accounts for the aircraft's heading by controlling the way the data is read out from the tape. Different heading angles result in the data being read from a different sequence of addresses. Since addresses exist only at discrete locations, the truncation of address locations causes an unavoidable change in the map shapes as the aircraft changes heading. The present invention stores terrain as polygons which are mathematically rotated as the aircraft changes attitude. The resolution is determined by number of bits used to represent the vertices of the polygons, not the number of storage addresses.
4. The '157 accounts for the roll attitude of the aircraft by mathematically rotating the screen data after it is projected. The '157 Patent does not show the display being responsive to the pitch angle of

the aircraft. In systems such as this the lack of fidelity is apparent to the user. People know what things are supposed to look like and how they are supposed to change perspective when they move. The present invention uses techniques that have long been used by the computer graphics industry to perform the mathematically correct transformation and projection.

5. The '157 shows only a single cockpit display while one of the embodiments of the present invention shows a stereographic head-mounted display with a head sensor. The pilot is presented with a synthesized view of the world that is responsive to wherever the pilot looks; the view is not blocked by the cockpit or other aircraft structures. This embodiment is not anticipated by the '157 patent.

The 1991 patent to Behensky et al. (U.S. Patent No. 5,005,148) shows a driving simulator for a video game. The road and other terrain are produced by mathematically transforming a three-dimensional polygon data base.

The first sales brochure from Atari Games Corp. is for a coin-operated game (Hard Drivin') produced in 1989 and relates to the '148 patent. The terrain is represented by polygons in a three-dimensional space. Each polygon is transformed mathematically according to the position and orientation of the player. After being tested to determine whether it is visible and having the appropriate illumination function performed, it is clipped and projected onto the display screen. These operations are in general use by the computer graphics industry and are well known to those possessing ordinary skill in the art.

The second sales brochure from Atari Games Corp. is for a coin-operated game (Steel Talons) produced in 1991 and which also relates to the '148 patent and the use of polygons to represent terrain and other objects.

The 1993 patent to Dawson et al. (U.S. Patent No. 5,179,638) shows a a method and apparatus for providing a texture mapped perspective view for digital map systems which includes a geometry engine that receives the elevation posts scanned from the cache memory by the shape address generator. A tiling engine is then used to transform the elevation posts into three-dimensional polygons. There are a number of differences between the '638 patent and the present invention:

1. The '638 Patent is for a digital map system only. The matter of how the location and attitude are selected is not addressed. The present invention uses a digital map as part of a system for presenting an aircraft pilot with a synthesized view of the world regardless of the actual visibility.
2. The '638 Patent stores the map as a collection of terrain points with associated altitudes, thereby requiring a large amount of data storage. The terrain points are transformed into polygons during program run-time, thereby adding to the processing burden. The present invention stores terrain data as a collection of polygons which results in a significant reduction of data base storage.
3. The present invention also teaches the use of a stereographic head-mounted display with a head sensor. The pilot is presented with a synthesized view of the world that is responsive to wherever the pilot looks; the view is not blocked by the cockpit or other aircraft structures. This embodiment is not anticipated by the '638 patent.

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Information Disclosure Statement

The 1994 patent to Hamilton et al. (U.S. Patent No. 5,296,854) shows a helicopter virtual display system in which the structual outlines corresponding to structual members forming the canopy structure are added to the head-up display in order to replace the canopy structure clues used by pilots which would otherwise be lost by the use of the head-up display.

The 1994 patent to Lewins (U.S. Patent No. 5,302,964) shows a head-up display for an aircraft and incorporates a cathode-ray tube image generator with a digital look-up table for distortion correction. An optical system projects an image formed on the CRT screen onto a holographic mirror combiner which is transparent to the pilot's direct view through the aircraft windshield.

The sales brochure from the Polhemus company shows the commercial availability of a position and orientation sensor which can be used on a head-mounted display.

The article from EDN magazine, January 7, 1993, pages 31-42, entitled "System revolutionizes surveying and navigation" is an overview of how the global positioning system (GPS) works and lists several manufacturers of commercially available receivers. The article also mentions several applications such as the use by geologists to monitor fault lines, by oil companies for off-shore oil explorations, for keeping track of lower-orbit satellites, by fleet vehicle operators to keep track of their fleet, for crop sprayers to spread fertilizer and pesticides more efficiently, and for in-car systems to display maps for automotive navigation.

The section from "Aviator's Guide to GPS" presents a history of the GPS program.

The sales brochure from Megellan Systems Corp. is for commercially available equipment comprising a GPS receiver with a moving map display. The map that is displayed is a flat map.

The sales brochure from Trimble Navigation is for a commercially available GPS receiver.

The sales brochure from the U.S. Geological Service shows the availability of Digital Elevation Models for all of the United States and its territories.

The second sales brochure from the U.S. Geological Service shows the availability of Digital Line Graph Models for all of the United States and its territories. The data includes: political and administrative boundaries; hydrography consisting of all flowing water, standing water, and wetlands; major transportation systems consisting of roads and trails, railroads, pipelines, transmission lines, and airports; and significant manmade structures.

The Washington Sectional Aeronautical Chart is a paper map published by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, that shows the complexity of the information that an aircraft pilot needs in order to fly in the area covered by the map. The other areas of the U.S. are covered by similar maps.

In the United States Patent and Trademark Office
Information Disclosure Statement

The sales brochure from Jeppesen Sanderson shows that the company makes its navigation data base available in computer readable form.

Very respectfully,

Jed Margolin

Jed Margolin

Applicant Pro Se

July 10, 1994
3570 Pleasant Echo
San Jose, CA 95148
(408) 238-4564

ENC: List of Prior Art & References

Sheet 1 of 6 08-513,298

LIST OF PRIOR ART CITED BY APPLICANT	ATTY DOCKET NO.	SERIAL NO. ~~08/274,394~~
	APPLICANT Jed Margolin	
	FILING DATE 07/11/94	GROUP 2304

MAIL ROOM JUL 12 1994 PAT. & TRADEMARK OFFICE

U.S. PATENT DOCUMENTS

Examiner Initial		Document Number	Date	Name	Class	Subclass	Filing Date If Appl.
TN	AA	4,445,118	04/84	Taylor et al.	342	357	
TN	AB	4,468,793	08/84	Johnson et al.	375	97	
TN	AC	4,485,383	11/84	Maher	342	352	
TN	AD	4,599,620	07/86	Evans	342	357	
TN	AE	5,101,356	03/92	Timothy et al.	364	449	
TN	AF	5,185,610	02/93	Ward et al.	342	357	
TN	AG	5,153,836	10/92	Fraughton et al.	364	461	
TN	AH	5,140,532	08/92	Beckwith et al.	395	101	
TN	AI	4,660,157	04/87	Beckwith et al.	364	522	
TN	AJ	5,005,148	04/91	Behensky et al.	364	578	
TN	AK	5,179,638	01/93	Dawson et al.	395	125	

FOREIGN PATENT DOCUMENTS

		Document Number	Date	Country	Class	Subclass	Translation Yes	No
	AL							
	AM							

OTHER PRIOR ART (Including Author, Title, Date, Pertinent Pages, etc.)

TN	AR	John Gallant, EDN magazine; January 7, 1993; pages 31-42 " System revolutionizes surveying and navigation "
TN	AS	Bill Clarke; Aviator's Guide to GPS; 1994; pages 2 and 3 " GPS Program History"

EXAMINER	DATE CONSIDERED
Tan Nguyen	11/06/94

Examiner: Initial if reference considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

LIST OF PRIOR ART CITED BY APPLICANT	ATTY DOCKET NO.	SERIAL NO. 08/274,394
	APPLICANT Jed Margolin	
	FILING DATE 07/11/94	GROUP 2304

U.S. PATENT DOCUMENTS

Examiner Initial		Document Number	Date	Name	Class	Subclass	Filing Date If Appl.
TN	AA	5,296,854	03/94	Hamilton et al.	340	980	
TN	AB	5,302,964	04/94	Lewins	345	7	
	AC						
	AD						
	AE						
	AF						
	AG						
	AH						
	AI						
	AJ						
	AK						

FOREIGN PATENT DOCUMENTS

		Document Number	Date	Country	Class	Subclass	Translation Yes	No
	AL							
	AM							

OTHER PRIOR ART (Including Author, Title, Date, Pertinent Pages, etc.)

TN	AR	Magellan Systems Corp, 960 Overland Ct, San Dimas, CA 91773 Sales brochure for GPS receiver with moving map display (MAP 7000) , Jan 1994
TN	AS	Trimble Navigation; 2105 Donley Dr, Austin TX 78758 Sales brochure for Airborne GPS receiver (TNL-1000) (No date is available)

EXAMINER	DATE CONSIDERED
[signature]	11/06/94

Examiner: Initial if reference considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

 08-513,298

LIST OF PRIOR ART CITED BY APPLICANT	ATTY DOCKET NO.	SERIAL NO. ~~08/274,394~~
	APPLICANT Jed Margolin	
	FILING DATE 07/11/94	GROUP 2304

U.S. PATENT DOCUMENTS

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	AA						
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FOREIGN PATENT DOCUMENTS

		Document Number	Date	Country	Class	Subclass	Translation Yes	No
	AL							
	AM							

OTHER PRIOR ART (Including Author, Title, Date, Pertinent Pages, etc.)

TN	AR	Jeppesen Sanderson, Inc; 55 Inverness Drive East, Englewood, CO 80112 Sales brochure for navigation data base in computer readable form
TN	AS	U.S. Geological Service, Earth Science Information Center, Menlo Park, CA Sales brochure for Digital Elevation Model data, June 1993

EXAMINER	DATE CONSIDERED
Tan Nguyen	11/06/94

Examiner: Initial if reference considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

 08-513,298

LIST OF PRIOR ART CITED BY APPLICANT	ATTY DOCKET NO.	SERIAL NO. ~~08/274,394~~
	APPLICANT Jed Margolin	
	FILING DATE 07/11/94	GROUP 2304

U.S. PATENT DOCUMENTS

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	AA						
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FOREIGN PATENT DOCUMENTS

		Document Number	Date	Country	Class	Subclass	Translation Yes	Translation No
	AL							
	AM							

OTHER PRIOR ART (Including Author, Title, Date, Pertinent Pages, etc.)

TN	AR	U.S. Geological Service, Earth Science Information Center, Menlo Park, CA Sales brochure for Digital Line Graph data, June 93
TN	AS	U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Washington Aeronautical Chart (paper map)

EXAMINER Jan Nguyen	DATE CONSIDERED 11/06/94

Examiner: Initial if reference considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

 08-513,298

LIST OF PRIOR ART CITED BY APPLICANT	ATTY DOCKET NO.	SERIAL NO. ~~08/274,344~~
	APPLICANT Jed Margolin	
	FILING DATE 08/11/94	GROUP 2304

U.S. PATENT DOCUMENTS

Examiner Initial		Document Number	Date	Name	Class	Subclass	Filing Date If Appl.
	AA						
	AB						
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	AD						
	AE						
	AF						
	AG						
	AH						
	AI						
	AJ						
	AK						

FOREIGN PATENT DOCUMENTS

		Document Number	Date	Country	Class	Subclass	Translation Yes	No
	AL							
	AM							

OTHER PRIOR ART (Including Author, Title, Date, Pertinent Pages, etc.)

TN	AR	Polhemus, P.O.Box 560, Colchester, VT Sales brochure for 3D head tracker , Jan 1994
TN	AS	Atari Games Corp, 675 Sycamore Dr, Milpitas, CA 95035; Sales brochure for coin-operated video game with 3D polygon-based graphics (Hard Drivin'), 1988

EXAMINER Tan Nguyen	DATE CONSIDERED 11/08/94

Examiner: Initial if reference considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

 08-513,298

LIST OF PRIOR ART CITED BY APPLICANT	ATTY DOCKET NO.	SERIAL NO. ~~08/274,394~~
	APPLICANT: Jed Margolin	
	FILING DATE 07/11/94	GROUP 2304

U.S. PATENT DOCUMENTS

Examiner Initial		Document Number	Date	Name	Class	Subclass	Filing Date If Appl.
	AA						
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FOREIGN PATENT DOCUMENTS

		Document Number	Date	Country	Class	Subclass	Translation Yes	No
	AL							
	AM							

OTHER PRIOR ART (Including Author, Title, Date, Pertinent Pages, etc.)

TN	AR	Atari Games Corp, 675 Sycamore Dr, Milpitas, CA 95035; Sales brochure for coin-operated video game with 3D polygon-based graphics (Steel Talons), 1991
	AS	

EXAMINER Jan Nguyen	DATE CONSIDERED 11/06/94

Examiner: Initial if reference considered, whether or not citation is in conformance with MPEP 609; Draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.

08/274,394

UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office
Address: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

SERIAL NUMBER	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.
08/274,394	07/11/94	MARGOLIN	

EXAMINER	
NGUYEN, T	
ART UNIT	PAPER NUMBER
2304	03

23M1/1109

JED MARGOLIN
3570 PLEASANT ECHO DRIVE
SAN JOSE CA 95148-1916

DATE MAILED: 11/09/94

This is a communication from the examiner in charge of your application.
COMMISSIONER OF PATENTS AND TRADEMARKS

☒ This application has been examined ☐ Responsive to communication filed on ______ ☐ This action is made final.

A shortened statutory period for response to this action is set to expire 3 month(s), 0 days from the date of this letter.
Failure to respond within the period for response will cause the application to become abandoned. 35 U.S.C. 133

Part I THE FOLLOWING ATTACHMENT(S) ARE PART OF THIS ACTION:

1. ☒ Notice of References Cited by Examiner, PTO-892.
2. ☒ Notice of Draftsman's Patent Drawing Review, PTO-948.
3. ☒ Notice of Art Cited by Applicant, PTO-1449. (6 sheets)
4. ☐ Notice of Informal Patent Application, PTO-152.
5. ☐ Information on How to Effect Drawing Changes, PTO-1474.
6. ☐ ______

Part II SUMMARY OF ACTION

1. ☒ Claims 1-13 are pending in the application.

   Of the above, claims ______ are withdrawn from consideration.

2. ☐ Claims ______ have been cancelled.

3. ☐ Claims ______ are allowed.

4. ☒ Claims 1-13 are rejected.

5. ☐ Claims ______ are objected to.

6. ☐ Claims ______ are subject to restriction or election requirement.

7. ☐ This application has been filed with informal drawings under 37 C.F.R. 1.85 which are acceptable for examination purposes.

8. ☐ Formal drawings are required in response to this Office action.

9. ☐ The corrected or substitute drawings have been received on ______. Under 37 C.F.R. 1.84 these drawings are ☐ acceptable; ☐ not acceptable (see explanation or Notice of Draftsman's Patent Drawing Review, PTO-948).

10. ☐ The proposed additional or substitute sheet(s) of drawings, filed on ______, has (have) been ☐ approved by the examiner; ☐ disapproved by the examiner (see explanation).

11. ☐ The proposed drawing correction, filed ______, has been ☐ approved; ☐ disapproved (see explanation).

12. ☐ Acknowledgement is made of the claim for priority under 35 U.S.C. 119. The certified copy has ☐ been received ☐ not been received ☐ been filed in parent application, serial no. ______ ; filed on ______.

13. ☐ Since this application apppears to be in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under Ex parte Quayle, 1935 C.D. 11; 453 O.G. 213.

14. ☐ Other

EXAMINER'S ACTION

PTOL-326 (Rev. 2/93)

Part III DETAILED ACTION

1. This application has been examined. Claims 1-13 are pending.

Specification

2. The title of the invention is not descriptive. A new title is required that is clearly indicative of the invention to which the claims are directed.

3. Applicant is reminded of the proper language and format of an Abstract of the Disclosure.

The abstract should be in narrative form and generally limited to a single paragraph on a separate sheet within the range of 50 to 250 words. It is important that the abstract not exceed 250 words in length since the space provided for the abstract on the computer tape used by the printer is limited. The form and legal phraseology often used in patent claims, such as "**means**" and "said", should be avoided (emphasis added). The abstract should describe the disclosure sufficiently to assist readers in deciding whether there is a need for consulting the full patent text for details.

The language should be clear and concise and should not repeat information given in the title. It should avoid using phrases which can be implied, such as, "The disclosure concerns," "The disclosure defined by this invention," "The disclosure describes," *etc.*

Appropriate correction is requested.

Claim Rejections - 35 USC § 112

4. Claim 1-13 are rejected under 35 U.S.C. § 112, second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which applicant regards as the invention.

4.1. As per claim 1 (as exemplary of claims 1, 7 and 13), lines 6-7 , the phrase "polygon data representing terrain and manmade structure" is unclear since there is no indication of what the polygon and manmade structure are. Clarification is requested. Furthermore, on lines 10-11, the phrase "difference operating features" is not defined properly. Moreover, the phrase "using said aircraft position data to access said terrain and manmade structure data from said digital data base" on lines 12-13 is unclear since there is no recitation of how to "access" the data from the digital data base by using the aircraft position data. Clarification is requested. In addition, on lines 14-15, the phrase "transform said terrain and manmade structure data to provide three dimensional projected image data" is also unclear since there is no indication of how to transform the terrain and manmade structure data to provide three dimensional projected image data. Clarification is needed.

4.2. As per claim 5 (as exemplary of claims 5 and 11), line 2, the phrase "the functions of pan, tilt, and zoom" is unclear since they are not defined properly.

4.3. As per claim 6 (as exemplary of claims 6 and 12), line 6, the phrase "the route ahead" has no antecedent basis.

4.4. As per claim 7, lines 20-21, the phrase "said aircraft's flight to be displayed at later time" is unclear since the "aircraft flight" is unclear and has no antecedent basis.

4.5. As per claim 13, the instant passage on lines 10-12 is not defined properly. Clarification is requested.

4.6. The remaining claims, not specifically mentioned, are rejected for incorporating the defects from their respective parent by dependency.

5. The following rejections are based on the examiner's best interpretation of the claims in light of the 35 U.S.C. 112 errors noted above.

Claim Rejections - 35 USC § 103

6. The following is a quotation of 35 U.S.C. § 103 which forms the basis for all obviousness rejections set forth in this Office action:

> A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negatived by the manner in which the invention was made.
>
> Subject matter developed by another person, which qualifies as prior art only under subsection (f) or (g) of section 102 of this title, shall not preclude patentability under this section where the subject matter and the claimed invention were, at the time the invention was made, owned by the same person or subject to an obligation of assignment to the same person.

7. Claims 1-12 are rejected under 35 U.S.C. § 103 as being unpatentable over Beckwith et al (4,660,157) in view of Behensky et al. (5,005,148) or a brochure from Atari Game Corp. (Hard Driving') or a brochure from Atari Game Corp. (Steel Talons).

7.1. With respect to claims 1, 5-7 and 11-12, Beckwith et al. discloses a digital system for producing a real time video display in perspective of terrain over which an aircraft is passing on the basis of compressed digital data stored on a cassette tape (see at least an abstract). Beckwith et al. discloses that the system includes a position determining means for locating the aircraft's position in three dimensions and an attitude determining means for determining the aircraft's orientation in three dimensional space (see at least figure 1 and columns 5 and 6). Beckwith et al. further discloses that the system includes a digital data base means for storing a compressed terrain data (see at least the abstract). Beckwith et al. also discloses a computer means for reading compressed terrain data from the digital data base means in a controlled manner based on the instantaneous geographical of the aircraft as provided by the aircraft navigation computer system, reconstructing the compressed data by suitable processing and writing the reconstructed data into a scene memory, and then providing a 3D perspective on the display (see at least columns 2 and 3).

Beckwith et al. does not explicitly disclose that a digital data base means containing polygon data representing terrain and manmade structures. However, Behensky et al. suggests a driving simulator for a video game which includes the road and other terrain are produced by mathematically transforming a three-dimensional polygon data base (see at least column 2, lines 33-38). The suggestion of Behensky et al. in at least column 2 would have motivated one of ordinary skill in the art to combine with the system of Beckwith et al. in order to provide a significant reduction of data base storage and a larger geographic areas can be stored so that it is not necessary to generate a data base of each mission. Similarly, the digital data base means containing polygon data representing terrain and manmade structures is also taught in a brochure from Atari Game Corp. (Hard Driving') or a brochure from Atari Game Corp. (Steel Talons). Thus, because of the motivation set forth above, it would have been obvious to a person of ordinary skill in the art at the time the invention was made to combine the teachings of Behensky et al. or the brochure from Atari Game Corp. (Hard Driving') or the brochure from Atari Game Corp. (Steel Talons) with the system of Beckwith et al.

7.2. With respect to claims 2-3 and 8-9, Beckwith et al. discloses the claimed invention as discussed above but does not explicitly discloses that the position determining means comprises a standard system for retrieving and processing data from the global positioning system and the attitude determining means comprises a standard avionics systems. However, the use of the standard system for retrieving and processing data from global positioning system and the standard avionics systems are well known effective and efficient means for determining the position and the orientation of the aircraft. For examples, the Maher patent (4,485,383) shows a receiver for receiving global positioning system and the Timothy patent shows a method for determining the orientation of a moving object form a single GPS receiver and producing roll, pitch, and yaw information. It would have been obvious to one of ordinary skill in the art at the time of the invention to utilize the global positioning system and the standard avionics system in such a system as taught through Beckwith et al. because it would produce high degree of accuracy in determining the position and orientation of the aircraft including roll, pitch, and yaw information.

7.3. With respect to claims 4 and 10, Beckwith et al. does not specifically disclose that the digital data base means comprises a CD rom disc and CD rom drive. However, the use of CD rom disc and CD rom drive for storing data is well known effective and efficient means for storing any data. It would have been obvious to one of ordinary skill in the art at the time of the invention to utilize CD rom disc and CD rom drive in such a system as taught through Beckwith et al. because it would permit high degree of accuracy in the storing and restoring data, random access to the data so that the requirements for cache storage are reduced.

8. Claim 13 is rejected under 35 U.S.C. § 103 as being unpatentable over Beckwith et al and Behensky et al. as applied to claims 1-12 above, and further in view of the sales brochure from the Polhemus company.

Beckwith et al. and Behensky et al. disclose the claimed invention except for a head mounted display means worn by the pilot and an attitude determining means for determining the orientation of the pilot's head in three dimensional space. However, the sales brochure from the Polhemus company suggests the commercial available of a position and orientation sensor which can be used on a head-mounted display. The suggestion of the Polhemus company would have motivated one of ordinary skill in the art to combine the teaching of Polhemus company with the system of Beckwith et al. in order to allow the pilot to have a complete range of motion to receive a synthesized view of the world, a complete unhindered by the aircraft structure. Thus, because of the motivation set forth above, it would have been obvious to a person of ordinary skill in the art at the time the invention was made to combine the teachings in Polhemus's brochure and Beckwith et al. patent.