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Assignments on the Web > **Patent Query**

Patent Assignment Abstract of Title

NOTE: Results display only for issued patents and published applications. For pending or abandoned applications please consult USPTO staff.

Total Assignments: 5

Patent #: 5904724 **Issue Dt:** 05/18/1999 **Application #:** 08587731 **Filing Dt:** 01/19/1996
Inventor: JED MARGOLIN
Title: METHOD AND APPARATUS FOR REMOTELY PILOTING AN AIRCRAFT

Assignment: 1
Reel/Frame: 020279/0850 **Recorded:** 12/21/2007 **Pages:** 2
Conveyance: ASSIGNMENT OF ASSIGNORS INTEREST (SEE DOCUMENT FOR DETAILS).
Assignor: MARGOLIN, JED **Exec Dt:** 07/20/2004
Assignee: OPTIMA TECHNOLOGY GROUP, INC.
1981 EMPIRE ROAD
RENO, NEVADA 89521-7430
Correspondent: JAY STELACONE
100 CAMBRIDGE STREET, SUITE 2101
BOSTON, MA 02114

Assignment: 2
Reel/Frame: 020218/0085 **Recorded:** 12/05/2007 **Pages:** 4
Conveyance: ASSIGNMENT OF ASSIGNORS INTEREST (SEE DOCUMENT FOR DETAILS).
Assignor: MARGOLIN, JED **Exec Dt:** 12/05/2007
Assignee: OPTIMA TECHNOLOGY CORPORATION (NV)
830 LAS VEGAS BOULEVARD SOUTH
C/O JOHN PETER LEE LIMITED
LAS VEGAS, NEVADA 89101
Correspondent: OPTIMA TECHNOLOGY CORPORATION (NV)
C/O JOHN PETER LEE LIMITED
830 LAS VEGAS BPULEVARD SOUTH
LAS VEGAS, NEVADA 89101

Assignment: 3
Reel/Frame: 020218/0089 **Recorded:** 12/05/2007 **Pages:** 5
Conveyance: ASSIGNMENT OF ASSIGNORS INTEREST (SEE DOCUMENT FOR DETAILS).
Assignor: MARGOLIN, JED BASED ON POWER OF ATTORNEY DATED JULY 20,2004 TO: OPTIMA TECHNOLOGY CORPORATION (CA) **Exec Dt:** 12/05/2007
Assignee: OPTIMA TECHNOLOGY CORPORATION (NV)
830 LAS VEGAS BOULEVARD SOUTH
C/O JOHN PETER LEE LIMITED
LAS VEGAS, NEVADA 89101
Correspondent: OPTIMA TECHNOLOGY COPORATION (NV)
C/O JOHN PETER LEE LIMITED
830 LAS VEGAS BPULEVARD SOUTH
LAS VEGAS, NEVADA 89101

Assignment: 4
Reel/Frame: 020227/0287 **Recorded:** 12/07/2007 **Pages:** 2
Conveyance: ASSIGNMENT OF ASSIGNORS INTEREST (SEE DOCUMENT FOR DETAILS).
Assignor: MARGOLIN, JED **Exec Dt:** 12/05/2007
Assignee: OPTIMA TECHNOLOGY CORPORATION (NV)
830 LAS VEGAS BOULEVARD SOUTH
C/O JOHN PETER LEE LIMITED
LAS VEGAS, NEVADA 89101
Correspondent: OPTIMA TECHNOLOGY CORPORATION (NV)
C/O JOHN PETER LEE LIMITED
830 LAS VEGAS BOULEVARD SOUTH
LAS VEGAS, NV 89101

Assignment: 5
Reel/Frame: 020279/0863 **Recorded:** 12/21/2007 **Pages:** 9
Conveyance: SUBMISSION TO CORRECT ERRORS IN PREVIOUSLY RECORDED DOCUMENTS PURSUANT TO MPEP 323.01(C)
Assignor: OPTIMA TECHNOLOGY GROUP, INC. **Exec Dt:** 12/21/2007

04780

Assignee: OPTIMA TECHNOLOGY GROUP, INC.
1981 EMPIRE ROAD
RENO, NEVADA 89521-7430

Correspondent: JAY STELACONE
100 CAMBRIDGE STREET, SUITE 2101
BOSTON, MA 02114

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> Business Directory > OPTIMA TECHNOLOGY CORPORATION

OPTIMA TECHNOLOGY CORPORATION

Description Edit

OPTIMA TECHNOLOGY CORPORATION in the Computer Peripheral Equipment, N.E.C. industry in IRVINE, CA. This company currently has approximately 250 to 500 employees and annual sales of $25,000,000 to $74,999,999.

Address Edit

2102 BUSINESS CENTER DR
IRVINE, CA 92612

Contact Edit

Phone: (949) 253-5768

Location Information

LINK ID: 123041027

Key Facts Edit

Industry:	Computer Peripheral Equipment, N.E.C.
Ownership:	Private
Year Founded:	1998
Sales Range:	$25,000,000 to $74,999,999
Employees:	250 to 500

People at this Company Edit

Name	**Title**
ROBERT ADAMS	CEO

Interact

Update OPTIMA TECHNOLOGY CORPORATION

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Map & Directions

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- ATT

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- Navigate OPTIMA TECHNOLOGY CORPORATION and its business relationships with our corporate tree information
- Get sales insights on OPTIMA TECHNOLOGY CORPORATION such as competitors, executives, financial information, and shipping spend
- Ensure OPTIMA TECHNOLOGY CORPORATION is a good credit risk with detailed business credit reports and payment behavior information

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Related Industries

- Application Software
- Information & Delivery Services
- Information Technology Services
- Multimedia & Graphics Software
- Security Software & Services
- Technical & System Software

Top Industries

- Aerospace/Defense - Major Diversified
- Auto Manufacturers - Major
- Biotechnology
- Business Software & Services
- Chemicals - Major Diversified
- Communication Equipment
- Conglomerates
- Diversified Computer Systems
- Diversified Investments
- Drug Manufacturers - Major
- Electric Utilities
- Food - Major Diversified
- Industrial Metals & Minerals
- Major Airlines
- Major Integrated Oil & Gas
- Money Center Banks
- Property & Casualty Insurance
- Semiconductor - Broad Line
- Telecom Services - Domestic

Complete Industry List...

Optima Technology Corporation Company Profile

Optima Technology can help you optimize your storage efforts. The company develops mass storage hardware and software products and related peripherals. Optima also offers professional services such as consulting, support, and training. The company's products include RAID subsystems, tape subsystems, and storage management software. Optima Technology was founded in 1990.

Contact Information

Address:	2222 Michelson Dr., Ste. 1830 Irvine, CA 92612
Phone:	949-476-0515
Fax:	949-476-0613

Financial Highlights

Fiscal Year End:	December
Revenue (2007):	40.40 M
Employees (2007):	375

Key People

- CEO: Robert Adams

Industry Information

Sector: Technology

Industry: Business Software & Services

Top Competitors

- EMC Corporation (emc)
- Hewlett-Packard Company (hpq)
- Symantec Corporation (symc)

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STD

U.S. District Court
DISTRICT OF ARIZONA (Tucson Division)
CIVIL DOCKET FOR CASE #: 4:07-cv-00588-RCC

Universal Avionics Systems Corporation v. Optima Technology Group, Inc. et al
Assigned to: Judge Raner C Collins
Cause: No cause code entered

Date Filed: 11/09/2007
Jury Demand: Both
Nature of Suit: 190 Contract: Other
Jurisdiction: Federal Question

Plaintiff

Universal Avionics Systems Corporation

represented by

Allan Andrew Kassenoff
Greenberg Traurig LLP
200 Park Ave
New York , NY 10166
212-801-9200
Fax: 212-801-6400
Email: kassenoffa@gtlaw.com
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ATTORNEY TO BE NOTICED

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Email: mandelr@gtlaw.com
ATTORNEY TO BE NOTICED

V.

Defendant

Optima Technology Group, Inc.

represented by **Jeffrey Lynn Willis**
Snell & Wilmer LLP
1 S Church Ave
Ste 1500
Tucson , AZ 85701-1612
520-882-1231
Fax: 520-884-1294
Email: jwillis@swlaw.com

Robert Alan Bernheim
Snell & Wilmer LLP
1 S Church Ave
Ste 1500
Tucson , AZ 85701-1612
520-882-1239
Fax: 520-884-1294
Email: rbernheim@swlaw.com
ATTORNEY TO BE NOTICED

Defendant

Optima Technology Corporation

Defendant

Jed Margolin

represented by **Jeffrey Lynn Willis**
(See above for address)
ATTORNEY TO BE NOTICED

Robert Alan Bernheim
(See above for address)
ATTORNEY TO BE NOTICED

Defendant

Optima Technology Corporation

ThirdParty Defendant

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Joachim L Naimer

ThirdParty Defendant

Jane Doe Naimer

ThirdParty Defendant

Frank E Hummel

ThirdParty Defendant

Jane Doe Hummel

ThirdParty Plaintiff

Optima Technology Group, Inc.

Cross Claimant

Optima Technology Group, Inc.

Counter Claimant

Optima Technology Group, Inc.

V.

Counter Defendant

Universal Avionics Systems Corporation

represented by **Allan Andrew Kassenoff**
(See above for address)
LEAD ATTORNEY
ATTORNEY TO BE NOTICED

Paul J Sutton
(See above for address)
LEAD ATTORNEY
ATTORNEY TO BE NOTICED

Scott Joseph Bornstein ,
(See above for address)
LEAD ATTORNEY
ATTORNEY TO BE NOTICED

E Jeffrey Walsh
(See above for address)
ATTORNEY TO BE NOTICED

Counter Claimant

Optima Technology Group, Inc.

represented by **Jeffrey Lynn Willis**
(See above for address)

Robert Alan Bernheim
(See above for address)
ATTORNEY TO BE NOTICED

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Counter Claimant

Jed Margolin represented by **Jeffrey Lynn Willis**
(See above for address)
ATTORNEY TO BE NOTICED

Robert Alan Bernheim
(See above for address)
ATTORNEY TO BE NOTICED

V.

Counter Defendant

Optima Technology Corporation

Date Filed	#	Docket Text
11/09/2007	1	SEALED COMPLAINT. Filing fee received: $ 350.00, receipt number 1549612, filed by Universal Avionics Systems Corporation. (Attachments: # 1 Exhibit Part 1 of 2# 2 Exhibit Part 2 of 2# 3 Summons OTC# 4 Summons OTG# 5 Summons JA# 6 Summons RA# 7 Civil Cover Sheet)(Walsh, E) Modified on 1/25/2008 (DNO, SEALED PER ORDER 39). Modified on 2/15/2008 (APJ,). (Entered: 11/09/2007)
11/09/2007		This case has been assigned to the Honorable Raner C. Collins. All future pleadings or documents should bear the correct case number: CIV-07-588-TUC-RCC. (GPA,) (Entered: 11/15/2007)
11/15/2007	2	Summons Issued as to Optima Technology Corporation. (GPA,). *** IMPORTANT: You must select "Document and stamps" or "Document and comments" on the print screen in order for the court seal to appear on the summons you print. (Entered: 11/15/2007)
11/15/2007	3	Summons Issued as to Optima Technology Group, Inc.. (GPA,). *** IMPORTANT: You must select "Document and stamps" or "Document and comments" on the print screen in order for the court seal to appear on the summons you print. (Entered: 11/15/2007)
11/15/2007	4	Summons Issued as to Jed Margolin. (GPA,). *** IMPORTANT: You must select "Document and stamps" or "Document and comments" on the print screen in order for the court seal to appear on the summons you print. (Entered: 11/15/2007)
11/15/2007	5	Summons Issued as to Robert Adams. (GPA,). *** IMPORTANT: You must select "Document and stamps" or "Document and comments" on the print screen in order for the court seal to appear on the summons you print. (Entered: 11/15/2007)
11/15/2007	6	Notice re electronically sending a magistrate election form to filer by Universal Avionics Systems Corporation (GPA,) (Entered: 11/15/2007)

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12/17/2007	7	Quarterly MOTION for Extension of Time To Answer based on Stipulation by Optima Technology Corporation, Robert Adams, Jed Margolin. (Attachments: # 1 Supplement Stipulation, # 2 Text of Proposed Order Order) (Chandler, Jeanna) (Entered: 12/17/2007)
12/19/2007	8	ORDER granting 7 Motion for Extension of Time. Dfts have up to 1/7/08 to serve/file their answer. Signed by Judge Raner C Collins on 12/18/07.(SSU,) (Entered: 12/19/2007)
01/04/2008	9	MOTION for Admission Pro Hac Vice as to attorney Scott J Bornstein on behalf of Universal Avionics Systems Corporation. (BAS,) (Entered: 01/04/2008)
01/04/2008	10	MOTION for Admission Pro Hac Vice as to attorney Paul J Sutton on behalf of Universal Avionics Systems Corporation. (BAS,) (Entered: 01/04/2008)
01/04/2008	11	MOTION for Admission Pro Hac Vice as to attorney Allan A Kassenoff on behalf of Universal Avionics Systems Corporation. (BAS,) (Entered: 01/04/2008)
01/04/2008		PRO HAC VICE FEE PAID. $ 100, receipt number PHX066316 as to Scott J Bornstein. (BAS,) (Entered: 01/04/2008)
01/04/2008		PRO HAC VICE FEE PAID. $ 100, receipt number PHX066315 as to Paul J Sutton. (BAS,) (Entered: 01/04/2008)
01/04/2008		PRO HAC VICE FEE PAID. $ 100, receipt number PHX066314 as to Allan A Kassenoff. (BAS,) (Entered: 01/04/2008)
01/04/2008	12	ORDER pursuant to General Order 05-25 granting 9 Motion for Admission Pro Hac Vice; granting 10 Motion for Admission Pro Hac Vice; granting 11 Motion for Admission Pro Hac Vice.Per the Court's Administrative Policies and Procedures Manual, applicant has five (5) days in which to register as a user of the Electronic Filing System. Registration to be accomplished via the court's website at www.azd.uscourts.gov. (BAS,)(This is a TEXT ENTRY ONLY. There is no.pdf document associated with this entry.) (Entered: 01/04/2008)
01/07/2008	13	MOTION to Dismiss Case by Optima Technology Group, Inc., Robert Adams. (Chandler, Jeanna) Modified on 1/9/2008 (SSU, DOCUMENT FILED WITH INCORRECT CASE NUMBER AND DOCUMENT NOT IN COMPLIANCE WITH LRCiv 7.1(c). ATTORNEY NOTICED). (Entered: 01/07/2008)
01/07/2008	16	SEALED LODGED Proposed Memorandum in Support of Motion to Dismiss Adams/Optima re: 14 MOTION to Seal Document re Memorandum in Support of Adams/Optima Motion to Dismiss. Document to be filed by Clerk if Motion to Seal is granted. Filed by Optima Technology Group, Inc., Robert Adams. (Chandler, Jeanna) (Entered: 01/07/2008)
01/07/2008	17	MOTION to Dismiss Case for Lack of Jurisdiction by Robert Adams. (Chandler, Jeanna) Modified on 1/9/2008 (SSU, DOCUMENT FILED WITH INCORRECT CASE NUMBER AND DOCUMENT NOT IN COMPLIANCE WITH LRCiv 7.1(c). ATTORNEY NOTICED). (Entered:

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		01/07/2008)
01/07/2008	20	SEALED LODGED Proposed Memorandum in Support of Adams Motion to Dismiss for Lack of Personal Jurisdiction re: 18 MOTION to Seal Document re Memorandum in Support of Motion To Dismiss. Document to be filed by Clerk if Motion to Seal is granted. Filed by Robert Adams. (Chandler, Jeanna) (Entered: 01/07/2008)
01/07/2008	21	MOTION to Dismiss Case for Lack of Jurisdiction by Jed Margolin. (Chandler, Jeanna) Modified on 1/9/2008 (SSU, DOCUMENT FILED WITH INCORRECT CASE NUMBER AND DOCUMENT NOT IN COMPLIANCE WITH LRCiv 7.1(c). ATTORNEY NOTICED). (Entered: 01/07/2008)
01/07/2008	24	SEALED LODGED Proposed Memorandum in Support of Margolins Motion to Dismiss re: 22 MOTION to Seal Document re Memorandum in Support of Margolins Motion to Dismiss. Document to be filed by Clerk if Motion to Seal is granted. Filed by Jed Margolin. (Chandler, Jeanna) (Entered: 01/07/2008)
01/07/2008	27	ANSWER to 1 Complaint, with Jury Demand by Optima Technology Group, Inc..(Chandler, Jeanna) Modified on 1/9/2008 (SSU, DOCUMENT FILED WITH INCORRECT CASE NUMBER AND DOCUMENT NOT IN COMPLIANCE WITH LRCiv 7.1(c). ATTORNEY NOTICED). (Entered: 01/07/2008)
01/07/2008	28	Corporate Disclosure Statement by Optima Technology Group, Inc. (Chandler, Jeanna) TEXT Modified on 1/8/2008 (SSU, DOCUMENT FILED WITH INCORRECT CASE NUMBER). (Entered: 01/07/2008)
01/08/2008	29	MOTION for Leave to File Excess Pages by Optima Technology Group, Inc., Robert Adams. (Attachments: # 1 Text of Proposed Order Proposed Order) (Chandler, Jeanna) Modified on 1/9/2008 (SSU, DOCUMENT FILED WITH INCORRECT CASE NUMBER AND DOCUMENT NOT IN COMPLIANCE WITH LRCiv 7.1(c). ATTORNEY NOTICED). (Entered: 01/08/2008)
01/08/2008	31	ORDER granting 14 Motion to Seal Document ; granting 18 Motion to Seal Document ; granting 22 Motion to Seal Document. Signed by Judge Raner C Collins on 1/8/08.(SGG,) (Entered: 01/09/2008)
01/08/2008	32	Sealed Document: Memorandum Per Order 31 filed by Optima Technology Group, Inc., Robert Adams. (SGG,) (Entered: 01/09/2008)
01/08/2008	33	Sealed Document: Memorandum Per Order 31 filed by Robert Adams. (SGG,) (Entered: 01/09/2008)
01/08/2008	34	Sealed Document: Memorandum Per Order 31 filed by Jed Margolin. (SGG,) (Entered: 01/09/2008)
01/09/2008	30	ORDER granting 29 Motion for Leave to File Excess Pages. Signed by Judge Raner C Collins on 1/9/08.(SSU,) (Entered: 01/09/2008)
01/22/2008	36	First MOTION for Extension of Time Extension of Deadline under Rule 14 (A)(1) *Unopposed* by Optima Technology Group, Inc.. (Attachments: # 1 Text

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		of Proposed Order)(Moomjian, Edward) DOCUMENT NOT IN COMPLIANCE WITH LRCiv7.1(c). ATTORNEY NOTICED. Modified on 1/24/2008 (SSU,). (Entered: 01/22/2008)
01/23/2008	37	ORDER granting 36 Motion for Extension of Time. Deadline for filing third party claims as a right is extended until and including 1/24/08. Signed by Judge Raner C Collins on 1/22/08.(SSU,) (Entered: 01/23/2008)
01/24/2008	38	AMENDED ANSWER to *COMPLAINT*, THIRD PARTY COMPLAINT against JOACHIM L. NAIMER, JANE DOE NAIMER, FRANK E. HUMMEL, JANE DOE HUMMEL, CROSSCLAIM against Optima Technology Corporation, COUNTERCLAIM against Universal Avionics Systems Corporation by Optima Technology Group, Inc.. (Moomjian, Edward) DOCUMENT FILED WITH INCORRECT CASE NUMBER. TEXT Modified on 1/25/2008 (SSU,). (Entered: 01/24/2008)
01/24/2008	39	SEALED ORDER granting 35 Motion to Seal Document ; denying 25 Motion to Seal Document. Signed by Judge Raner C Collins on 01/23/08.(DNO,) (Entered: 01/25/2008)
01/30/2008	40	Notice re Summons by Optima Technology Group, Inc. (Attachments: # 1 Summons)(Moomjian, Edward) (Entered: 01/30/2008)
01/30/2008	41	Summons Issued as to Optima Technology Group, Inc., Optima Technology Corporation. (Attachments: # 1 Summons)(BJW,). *** IMPORTANT: You must select "Document and stamps" or "Document and comments" on the print screen in order for the court seal to appear on the summons you print. (Entered: 01/30/2008)
02/06/2008	42	Notice re Summons to Frank E. Hummel by Optima Technology Group, Inc. (Attachments: # 1 Summons Jane Doe Hummel, # 2 Summons Joachim L. Naimer, # 3 Summons Jane Doe Naimer)(Chandler, Jeanna) (Entered: 02/06/2008)
02/06/2008	43	Summons Issued as to Joachim L Naimer, Jane Doe Naimer, Frank E Hummel, Jane Doe Hummel. (Attachments: # 1 Summons, # 2 Summons, # 3 Summons)(BJW,). *** IMPORTANT: You must select "Document and stamps" or "Document and comments" on the print screen in order for the court seal to appear on the summons you print. (Entered: 02/06/2008)
02/11/2008	48	SEALED MOTION to Seal Document by Universal Avionics Systems Corporation. (DNO,) (Entered: 02/15/2008)
02/13/2008	44	AFFIDAVIT of Phyllis Callahan *re Affidavit of Process Server as to Service Upon Reza Zandian (Statutory Agent) for Optima Technology Corporation* by Cross Claimant Optima Technology Group, Inc.. (Chandler, Jeanna) (Entered: 02/13/2008)
02/13/2008	45	MOTION for Extension of Time to File Answer re Counterclaims and Third-Party Claims by Universal Avionics Systems Corporation. (Attachments: # 1 Supplement Stipulation re Enlargement of Time for Plaintiff Counterdefendant and Third-Party Defendants to Answer or Otherwise Respond to Counterclaims and Third-Party Claims, # 2 Text of Proposed

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		Order Order Enlarging Time)(Walsh, E) (Entered: 02/13/2008)
02/13/2008	46	Corporate Disclosure Statement by Universal Avionics Systems Corporation. (Walsh, E) (Entered: 02/13/2008)
02/14/2008	47	ORDER granting 45 Motion for Extension of Time to Answer. Joachim L Naimer answer due 4/14/2008; Jane Doe Naimer answer due 4/14/2008; Frank E Hummel answer due 4/14/2008; Jane Doe Hummel answer due 4/14/2008; Universal Avionics Systems Corporation answer due 3/18/2008. Signed by Judge Raner C Collins on 2/14/08.(SSU,) (Entered: 02/14/2008)
02/15/2008	49	SUMMONS Returned Executed by Universal Avionics Systems Corporation. Jed Margolin served on 11/26/2007. (Walsh, E) (Entered: 02/15/2008)
02/15/2008	50	SUMMONS Returned Executed by Universal Avionics Systems Corporation. Optima Technology Corporation served on 11/28/2007. (Walsh, E) (Entered: 02/15/2008)
02/15/2008	51	SEALED ORDER granting 48 Motion to Seal Document. Signed by Judge Raner C Collins on 02/15/08.(SGG,) (Entered: 02/20/2008)
02/15/2008	52	SEALED RESPONSE to Motion re 13 MOTION to Dismiss Case filed by Universal Avionics Systems Corporation., Sealed per Order 51 . (SGG,) (Entered: 02/20/2008)
02/15/2008	53	SEALED RESPONSE to Motion re 17 MOTION to Dismiss Case for Lack of Jurisdiction filed by Universal Avionics Systems Corporation. Sealed per Order 51 . (SGG,) (Entered: 02/20/2008)
02/15/2008	54	SEALED RESPONSE to Motion re 21 MOTION to Dismiss Case for Lack of Jurisdiction filed by Universal Avionics Systems Corporation. Sealed per Order 51 . (SGG,) (Entered: 02/20/2008)
02/15/2008	55	SEALED MOTION to Expedite Discovery by Universal Avionics Systems Corporation. Sealed per Order 51 . (SGG,) (Entered: 02/20/2008)
02/15/2008	56	Sealed Document: Memorandum and Support of 55 filed by Universal Avionics Systems Corporation. Sealed per Order 51 . (SGG,) (Entered: 02/20/2008)
02/15/2008	57	Sealed Document: Declaration filed by Universal Avionics Systems Corporation. Sealed per Order 51 (Attachments: # 1 Exhibit, # 2 Exhibit, # 3 Exhibit)(SGG,) (Entered: 02/20/2008)
02/15/2008	58	Sealed Document: Declaration filed by Universal Avionics Systems Corporation. Sealed per Order 51 . (SGG,) (Entered: 02/20/2008)
02/28/2008	59	MOTION to Expedite Motion for Extension of Time by Optima Technology Group, Inc., Robert Adams, Jed Margolin. (Moomjian, Edward) (Entered: 02/28/2008)
02/28/2008	60	MOTION for Extension of Time Extension of Time *Motion for Extension of Time to Submit Replies* by Optima Technology Group, Inc., Robert Adams, Jed Margolin. (Attachments: # 1 Text of Proposed Order)(Moomjian, Edward) (Entered: 02/28/2008)

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02/28/2008	61	ORDER granting 59 Motion to Expedite.; granting 60 Motion for Extension of Time. Dfts have 30 days up to and including 3/31/08 to file their replies in support of Motions to Dismiss and Response/Opposition to the Motion for Expedited Discovery. Signed by Judge Raner C Collins on 2/28/08.(SSU,) (Entered: 02/28/2008)
02/28/2008	62	MEMORANDUM re: In Opposition to Motion for Extension of Time by Plaintiff Universal Avionics Systems Corporation. (Walsh, E) (Entered: 02/28/2008)
03/03/2008	64	SEALED ORDER granting 63 Motion to Withdraw. Signed by Judge Raner C Collins on 02/28/08.(DNO,) (Entered: 03/05/2008)
03/18/2008	65	ANSWER to 38 Amended Answer to Complaint, Third Party Complaint, Crossclaim, Counterclaim,,,, by Universal Avionics Systems Corporation. (Walsh, E) (Entered: 03/18/2008)
04/01/2008	66	NOTICE of Appearance by Jeffrey Lynn Willis on behalf of Optima Technology Group, Inc., Robert Adams, Jed Margolin (Willis, Jeffrey) (Entered: 04/01/2008)
04/01/2008	67	STIPULATION *for 72-Hour Extension of Time to File Replies in Support of Motions to Dismiss and Response to Plaintiff's Motion for Expedited Discovery (Second Request)* by Optima Technology Group, Inc., Robert Adams, Jed Margolin. (Attachments: # 1 Text of Proposed Order)(Willis, Jeffrey) (Entered: 04/01/2008)
04/01/2008	68	ORDER re 67 STIPULATION for 72-Hour Extension of Time to File Replies in Support of Motions to Dismiss and Response to Plaintiff's Motion for Expedited Discovery, due 4/3/08. Signed by Judge Raner C Collins on 4/1/08. (KMF,) (Entered: 04/01/2008)
04/02/2008	69	NOTICE of Appearance by Jeffrey Lynn Willis on behalf of Optima Technology Group, Inc., Robert Adams, Jed Margolin (Willis, Jeffrey) (Entered: 04/02/2008)
04/02/2008	70	APPLICATION for Entry of Default by Defendants Optima Technology Group, Inc., against Optima Technology Corporation, Inc.. (Attachments: # 1 Text of Proposed Order Proposed Entry of Default)(Willis, Jeffrey) Modified on 4/2/2008 to correct applicant (BJW,). (Entered: 04/02/2008)
04/03/2008	71	REPLY in Support re 21 MOTION to Dismiss Case for Lack of Jurisdiction *and Request for Stay of Proceedings on Motion to Dismiss* filed by Optima Technology Group, Inc., Robert Adams, Jed Margolin. (Willis, Jeffrey) (Entered: 04/03/2008)
04/03/2008	72	REPLY in Support re 13 MOTION to Dismiss Case filed by Optima Technology Group, Inc., Robert Adams, Jed Margolin. (Willis, Jeffrey) (Entered: 04/03/2008)
04/03/2008	73	RESPONSE to Motion re 55 MOTION to Expedite Discovery filed by Optima Technology Group, Inc., Robert Adams, Jed Margolin. (Willis, Jeffrey) (Entered: 04/03/2008)

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04/07/2008	74	Clerk's ENTRY OF DEFAULT as to Optima Technology Corporation (PAB,) (Entered: 04/07/2008)
04/09/2008	75	ORDER granting 13 Motion to Dismiss Case and as amended by 72 Reply; Counts 5, 6, 7 of Plaintiff's Complaint are dismissed without prejudice to Plaintiff refiling thises claims in state court. Counts 2-4 and 7-12 of Defendants' state law counterclaims, cross-claims and third-party claims are dismissed without prejudice. Ordered denying as moot 17 Motion to Dismiss Case for Lack of Jurisdiction; dft Adams is dismissed. Ordered denying 21 Motion to Dismiss Case for Lack of Jurisdiction and 71 Request for a Stay of Proceedings. Signed by Judge Raner C Collins on 4/9/08.(SSU,) (Entered: 04/09/2008)
04/10/2008	76	APPLICATION for Entry of Default by Defendant Optima Technology Group, Inc. against Optima Technology Corporation. (Attachments: # 1 Exhibit A, # 2 Exhibit B, # 3 Text of Proposed Order)(Willis, Jeffrey) (Entered: 04/10/2008)
04/14/2008	77	Clerk's ENTRY OF DEFAULT as to Optima Technology Corporation. (SSU,) (Entered: 04/14/2008)
04/29/2008	78	STIPULATION by Optima Technology Group, Inc., Optima Technology Corporation, Universal Avionics Systems Corporation, Robert Adams, Jed Margolin. (Attachments: # 1 Text of Proposed Order Order)(Walsh, E) (Entered: 04/29/2008)
05/06/2008	79	ORDER denying 55 Motion to Expedite, pursuant to Stipulation 78 . Pla Universal Avionics Systems Corporation may file an amended complaint to reflect the effect of this Court's 4/9/08 Order on or before 5/9/08. Dfts Optima Technology Group and Jed Margolin will respond to the amended complaint within ten days of service. Universal will file a reply to any counterclaims within ten days after being served with such counterclaims. Any and all responsive pleadings that were or may have been due before the date of this Order are vacated in favor of the schedule set forth herein. Signed by Judge Raner C Collins on 4/29/08.(JEMB,) (Entered: 05/06/2008)
05/13/2008	82	**PHRASE "OR PATENT TROLL" PG1 LINE 24, & PARAGRAPHS 37-43 STRIKEN PER ORDER 101 **Sealed Document: FIRST AMENDED COMPLAINT filed by Universal Avionics Systems Corporation. (JEMB,) Modified on 7/7/2008 (JEMB,TO REFLECT STRICKEN SECTIONS). (Entered: 05/16/2008)
05/14/2008	81	ORDER granting 80 Motion to Seal Document. Signed by Judge Raner C Collins on 5/14/08.(JEMB,) (Entered: 05/16/2008)
05/16/2008	83	CERTIFICATE OF SERVICE by Universal Avionics Systems Corporation (Walsh, E) (Entered: 05/16/2008)
05/20/2008	84	Sealed MOTION to Seal Document re Motion to Unseal Chandler & Udall, LLP'S Ex Parte Motion to Withdraw as Counsel by Universal Avionics Systems Corporation. (Attachments: # 1 Text of Proposed Order)(Walsh, E) Modified on 5/21/2008 to seal document(PAB,). (Entered: 05/20/2008)

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05/20/2008	85	SEALED LODGED Proposed Motion to Unseal Chandler & Udall, LLP's Ex Parte Motion to Withdraw as Counsel re: 84 MOTION to Seal Document re Motion to Unseal Chandler & Udall, LLP'S Ex Parte Motion to Withdraw as Counsel. Document to be filed by Clerk if Motion to Seal is granted. Filed by Universal Avionics Systems Corporation. (Walsh, E) (Entered: 05/20/2008)
05/20/2008	86	SEALED LODGED Proposed Declaration of Allan A. Kassenoff in Support of Plaintiff Universal Avionics Systems Corportation's Motion to Unseal Chandler & Udall, LLP's Ex Parte Motion to Withdraw as Counsel re: 84 MOTION to Seal Document re Motion to Unseal Chandler & Udall, LLP'S Ex Parte Motion to Withdraw as Counsel. Document to be filed by Clerk if Motion to Seal is granted. Filed by Universal Avionics Systems Corporation. (Attachments: # 1 Exhibit)(Walsh, E) (Entered: 05/20/2008)
05/21/2008	89	ORDER granting 84 Motion to Seal Document. Signed by Judge Raner C Collins on 5/20/08.(JEMB,) (Entered: 05/22/2008)
05/21/2008	90	MOTION to Unseal Document re Chandler & Udall, LLP's Ex Parte Motion to Withdraw as Counsel by Universal Avionics Systems Corporation. (JEMB,) (Entered: 05/22/2008)
05/21/2008	91	Sealed Document: Declaration filed by Universal Avionics Systems Corporation. (Attachments: # 1 Exhibit)(JEMB,) (Entered: 05/22/2008)
05/22/2008	87	MOTION to Strike *Allegations From Amended Complaint* by Optima Technology Group, Inc., Jed Margolin. (Bernheim, Robert) (Entered: 05/22/2008)
05/22/2008	88	Additional Attachments to Main Document re 87 MOTION to Strike *Allegations From Amended Complaint Proposed Order Granting Defendants' Motion to Strike Allegations from Amended Complaint* by Defendants Optima Technology Group, Inc., Jed Margolin. (Bernheim, Robert) (Entered: 05/22/2008)
05/29/2008	92	RESPONSE in Opposition re 90 MOTION to Unseal Document re Chandler & Udall, LLP's Ex Parte Motion to Withdraw as Counsel filed by Optima Technology Group, Inc., Jed Margolin. (Bernheim, Robert) (Entered: 05/29/2008)
06/04/2008	93	RESPONSE in Opposition re 87 MOTION to Strike *Allegations From Amended Complaint* filed by Universal Avionics Systems Corporation. (Walsh, E) (Entered: 06/04/2008)
06/05/2008	94	REPLY in Support re 90 MOTION to Unseal Document re Chandler & Udall, LLP's Ex Parte Motion to Withdraw as Counsel filed by Universal Avionics Systems Corporation. (Walsh, E) (Entered: 06/05/2008)
06/09/2008	96	SEALED ORDER denying 90 Motion to Unseal Document. Signed by Judge Raner C Collins on 6/9/08.(JEMB,) (Entered: 06/12/2008)
06/11/2008	95	Notice re Joint Rule 26(f) Report and Respective Case Management Plans by Optima Technology Group, Inc., Universal Avionics Systems Corporation (Willis, Jeffrey) (Entered: 06/11/2008)

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06/18/2008	97	REPLY to Response to Motion re 87 MOTION to Strike *Allegations From Amended Complaint* filed by Optima Technology Group, Inc., Jed Margolin. (Bernheim, Robert) (Entered: 06/18/2008)
06/18/2008	98	MOTION for Default Judgment as to Cross-Defendants Optima Technology Corp. (a CA corp.) and Optima Technology Corp.(a NV corp.) by Optima Technology Group, Inc., Robert Adams, Jed Margolin..(Attachments: # 1 Text of Proposed Order [Proposed] Form of Judgment)(Bernheim, Robert) (Entered: 06/18/2008)
06/23/2008	99	RESPONSE in Opposition re 98 MOTION for Default Judgment as to Cross-Defendants Optima Technology Corp. (a CA corp.) and Optima Technology Corp.(a NV corp.) MOTION for Default Judgment as to Cross-Defendants Optima Technology Corp. (a CA corp.) and Optima Technology Corp.(a NV corp.) filed by Universal Avionics Systems Corporation. (Walsh, E) (Entered: 06/23/2008)
06/27/2008	100	Reply re 99 Response in Opposition to Motion, by Defendant Optima Technology Group, Inc.. (Bernheim, Robert) (Entered: 06/27/2008)
07/07/2008	101	ORDER granting in part and denying in part 87 Motion to Strike, Plaintiff may file an amended complaint by 7/15/08; granting 98 Motion for Default Judgment against Cross-Dfts Optima Technology Corporation, a CA Corporation, and Optima Technology Corporation, a NV Corporation.Signed by Judge Raner C Collins on 7/2/08.(SSU,) (Entered: 07/07/2008)
07/08/2008	102	REQUEST *For Entry of Separate Judgment Under Rule 58(d)* by Defendants Optima Technology Group, Inc., Robert Adams, Jed Margolin. (Attachments: # 1 Proposed Form of Judgment)(Bernheim, Robert) (Entered: 07/08/2008)
07/10/2008	103	Notice re of Service of Defendant Optima Technology Group, Inc.'s First Set of Interrogatories to Plaintiff by Optima Technology Group, Inc. (Willis, Jeffrey) (Entered: 07/10/2008)
07/15/2008	104	AMENDED COMPLAINT *Second* against Optima Technology Corporation, Optima Technology Group, Inc., Jed Margolin;Jury Demand, filed by Universal Avionics Systems Corporation.(Walsh, E) (Entered: 07/15/2008)
07/15/2008	105	AFFIDAVIT of Process Server Dean Nichols *on Mercury Computer Systems, Inc.* by Plaintiff Universal Avionics Systems Corporation. (Attachments: # 1 Exhibit Subpoena)(Walsh, E) (Entered: 07/15/2008)
07/15/2008	106	AFFIDAVIT of Process Server Ronald Bodtke *for Service on Reza Zandian* by Plaintiff Universal Avionics Systems Corporation. (Attachments: # 1 Exhibit Subpoena)(Walsh, E) (Entered: 07/15/2008)
07/15/2008	107	NOTICE of Deposition of Jed Margolin, filed by Universal Avionics Systems Corporation. (Walsh, E) (Entered: 07/15/2008)
07/15/2008	108	NOTICE of Deposition of Robert Adams, filed by Universal Avionics Systems Corporation. (Walsh, E) (Entered: 07/15/2008)
07/15/2008	109	Notice re Service of Plaintiff's First Set of Interrogatories to Defendant Optima Technology Group, Inc. by Universal Avionics Systems Corporation

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		(Walsh, E) TEXT HAS BEEN MODIFED TO REFLECT CORRECT DOCUMENT TITLE, PER ATTORNEY. Modified on 7/16/2008 (SSU,). (Entered: 07/15/2008)
07/16/2008	110	Notice re Service of Plaintiff's First Request for Production of Documents to Defendant Optima Technology Group, Inc. by Universal Avionics Systems Corporation by Universal Avionics Systems Corporation (Walsh, E) (Entered: 07/16/2008)
07/18/2008	111	NOTICE of Deposition of UAS, filed by Optima Technology Group, Inc.. (Willis, Jeffrey) (Entered: 07/18/2008)
07/18/2008	112	NOTICE of Deposition of Joaquin Naimer, filed by Optima Technology Group, Inc.. (Willis, Jeffrey) (Entered: 07/18/2008)
07/18/2008	113	NOTICE of Deposition of Don Berlin, filed by Optima Technology Group, Inc.. (Willis, Jeffrey) (Entered: 07/18/2008)
07/18/2008	114	NOTICE of Deposition of Frank Hummel, filed by Optima Technology Group, Inc.. (Willis, Jeffrey) (Entered: 07/18/2008)
07/21/2008	115	MOTION for Reconsideration re Of the Court's Default Ruling Against Optima Technology Corporation Filed July7, 2008 by Universal Avionics Systems Corporation. (Attachments: # 1 Exhibit A)(Mandel, Robert) (Entered: 07/21/2008)
07/23/2008	116	MOTION for Hearing or Conference re: Rule 16 Conference by Optima Technology Group, Inc., Jed Margolin. (Attachments: # 1 Exhibit A, # 2 Exhibit B, # 3 Text of Proposed Order)(Willis, Jeffrey) (Entered: 07/23/2008)
07/25/2008	117	APPLICATION for Entry of Default by Plaintiff Universal Avionics Systems Corporation against Optima Technology Corporation. (Attachments: # 1 Text of Proposed Order Entry of Default)(Mandel, Robert) (Entered: 07/25/2008)
07/25/2008	118	DECLARATION of Declaration of Allan A. Kassenoff in Support of Plaintiff's Application for Entry of Default re 117 Application for Entry of Default by Plaintiff Universal Avionics Systems Corporation. (Attachments: # 1 Exhibit A, # 2 Exhibit B)(Mandel, Robert) (Entered: 07/25/2008)
07/28/2008	119	RESPONSE in Opposition re 116 MOTION for Hearing or Conference re: Rule 16 Conference *and Expedited Stay of Proceedings Pending Conference* filed by Universal Avionics Systems Corporation. (Attachments: # 1 Exhibit A, # 2 Exhibit B, # 3 Exhibit C)(Mandel, Robert) (Entered: 07/28/2008)
07/29/2008	120	Clerk's ENTRY OF DEFAULT as to Optima Technology Corporation (SSU,) (Entered: 07/29/2008)
07/29/2008	121	ORDER granting in part and denying in part 116 Motion; Court will set scheduling conference but will not grant a stay of the proceedings. Telephonic Scheduling Conference set for 8/28/2008 10:00 AM before Judge Raner C Collins' law clerk, Isaac Rothschild. Further ordered, parties file with the Court a joint report reflecting the results of the conference by 8/25/08. Signed by Judge Raner C Collins on 7/29/08.(SSU,) (Entered: 07/29/2008)

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07/29/2008	122	*Optima Technology Group and Jed Margolin's* ANSWER to 104 Amended Complaint *and*, COUNTERCLAIM against Optima Technology Corporation by Optima Technology Group, Inc., Jed Margolin.(Bernheim, Robert) (Entered: 07/29/2008)
07/31/2008	123	MOTION FOR DEFAULT JUDGMENT by Plaintiff Universal Avionics Systems Corporation against Optima Technology Corporation. (Mandel, Robert) EVENT AND TEXT MODIFIED FROM Application for Default Judgment TO Motion for Default Judgment. Modified on 8/5/2008 (SSU,). (Entered: 07/31/2008)
08/06/2008	124	Notice re Service of Requests for Production to Garmin International, Inc. by Optima Technology Group, Inc., Jed Margolin (Bernheim, Robert) (Entered: 08/06/2008)
08/06/2008	125	Notice re Answers to Universal Avionics Systems Corporation's First Set of Interrogatories by Optima Technology Group, Inc. (Willis, Jeffrey) (Entered: 08/06/2008)
08/12/2008	126	Reply *TO DEFENDANT OPTIMA TECHNOLOGY GROUP, INC.S COUNTERCLAIMS* by Plaintiff Universal Avionics Systems Corporation. (Mandel, Robert) (Entered: 08/12/2008)
08/13/2008	127	Notice re SERVICE OF OBJECTIONS AND RESPONSES TO OPTIMA TECHNOLOGY GROUP, INC.'S FIRST SET OF INTERROGATORIES by Universal Avionics Systems Corporation (Mandel, Robert) (Entered: 08/13/2008)

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GA Riding 'Highway-in-the-Sky'

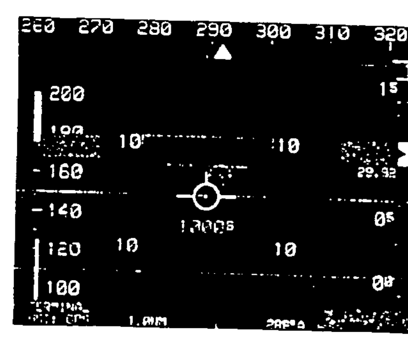
General aviation sector reaps the benefits of research originally conducted for military, commercial transport cockpits

BRUCE D. NORDWALL/WASHINGTON and OKLAHOMA CITY

General aviation aircraft are finally catching up with some of the advances found in the latest commercial transports and military cockpits, and in one particular sphere—display innovations—GA is actually taking the lead.

Researchers in industries and universities around the world have been pursuing a more intuitive guidance display for pilots for years. In general, this elusive presentation is referred to as highway-in-the-sky (HITS) (*AW&ST* Apr. 20, 1998, p. 58). In a twist that may foreshadow future advances, it was a general aviation aircraft that received the FAA's first certification of HITS technology for navigation guidance.

Instead of following course deviation indicators and altimeters, a pilot using this HITS presentation flies through a series of 3D boxes on a multifunction display. By maneuvering through the 400 X 320-ft. boxes spaced at 2,000-ft. intervals along the planned GPS route of flight, the pilot keeps the aircraft on course and altitude, which is particularly helpful for a descending, curved instrument approach.



Flying through "boxes in the sky" keeps pilots on course and altitude during a simulated curved instrument approach down the mountainous Gastineau Channel to Juneau, Alaska.

L.A.B. Flying Service's Piper Seneca made the first commercial revenue flight using HITS in Juneau, Alaska, on Mar. 31. It followed an optimized area navigation (RNAV) route through airspace that would be inaccessible with conventional avionics.

The system was built by Chelton Flight Systems as part of the second 04800 phase of the imaginative Capstone program, an FAA industry/academic partnership in Alaska. The cockpit employs a Chelton FlightLogic electronic flight information system-synthetic vision (EFIS-SV) using two glass displays, one for primary flight guidance and one for navigation.

The big innovation is the use of synthetic vision symbology to present information to pilots. The initial EFIS systems digitally replicated the rudimentary attitude and flight-director symbols of electro-mechanical instruments from an earlier era. Now, in addition to the flight path, pilots see a real-time 3D view of the terrain and obstacles on the primary flight display. These are complemented by a moving map on the navigation display and by aural terrain warnings.

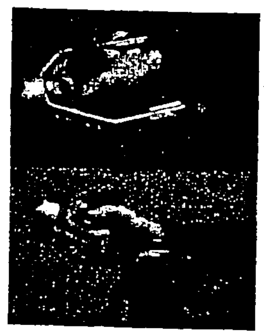
Among the other "firsts" claimed by Capstone Phase II on the Juneau flight were the use of forward-looking 3D terrain and HUD symbology on a certified primary flight display, and commercial use of the GPS wide-area augmentation system (WAAS).

Capstone has equipped three aircraft in Alaska with the Chelton Flight Systems' cockpit, and plans to outfit every commercial operator in SE Alaska within the next 18 months. The contract for 125 aircraft could expand to up to 200, according to Gordon Pratt, Chelton's president. The FAA is providing the equipment at no charge in Alaska to any commuter and on-demand (FAA Part 135) operator of fixed-wing aircraft or helicopters. A supplemental type certificate for helicopters was scheduled to be delivered on May 31. An additional 10 aircraft are being outfitted in the contiguous U.S., Pratt said, but at the expense of aircraft owners.

The first phase of the Capstone Program started as a demonstration that equipped a number of commuter and air taxi aircraft in the Yukon-Kuskokwim River delta area with a low-cost GPS, a terrain database, data link and Automatic Dependent Surveillance-Broadcast (ADS-B) equipment (*AW&ST* Sept. 18, 2000, p. 68). With GPS as the enabling technology, that phase indicated that a low-cost system could give bush pilots many of the safety benefits long-standard for commercial jet transports. The emphasis was on reducing controlled flight into terrain accidents for these pilots, who usually operate out of the range of navigation aids or radar help from ATC. Phase II with HITS and synthetic vision greatly expands those capabilities.

CAMI tested a four-axis side-arm controller in a simulator as a replacement for stick and throttle in a fly-by-wire performance control system.

The navigation display shows GPS WAAS position and an approach not possible with conventional navigation aids due to a 20-30-deg. turn after the GASTN waypoint to align with the runway.



The next major safety enhancement for GA aircraft could come from "performance control," according to Dennis B. Beringer, lead scientist for flight deck research at the FAA's Civil Aeromedical Institute (CAMI) in Oklahoma City. While known more for assisting FAA's Aircraft Certification Service and Flight Standards in defining requirements for both aircraft and pilots, CAMI is also an active partner in human factors research to improve cockpits.

With **performance control,** non-pilots could learn to fly *a simulator in 15 min.*

The performance-control concept was introduced in the 1970s, before electronics were sufficiently advanced for implementation. Beringer said that now some of the fly-by-wire military and commercial aircraft use what could be legitimately called performance-control logic, which not only make aircraft easier to fly, but can also add flight envelope protection.

With conventional flight controls, a pilot has direct command of the aerodynamic surfaces. With performance control, his movements would be transmitted via a fuzzy-logic controller to a flight management system or an auto pilot that would guide the aircraft to carry out the desired performance goal. But unlike a simple autopilot, which directs a change in heading at a limited rate of turn, performance-control logic changes control laws so that a pilot commands the rate of turn and bank, and rate of climb or descent. It simplifies command of more complicated maneuvers, and is a compromise between automated maneuvering and manual flight control, Beringer said. Safety is further enhanced using a self-centering (spring-loaded) side stick which returns to the centered position when the pilot relaxes pressure, thus bringing the aircraft to straight and level flight.

The reduced number of control movements is one reason flying is easier. Going into a turn with conventional controls, the pilot has to initiate the roll, and then neutralize the ailerons when he achieves the desired bank angle. But with performance controls, one movement establishes the desired bank angle/turn rate. One downside to performance control with envelope protection is the inability to do aerobatics, such as an aileron roll or loop, Beringer said.

In the four-axis side-arm controller (above), rotating the wrist governs the rate of turn, flexing the wrist vertically directs the rate of climb or descent, and fore and aft movement varies the airspeed. Interest in performance controls was renewed with NASA's Agate (Advanced General Aviation Transport Experiments) program, which was concerned with simplifying the flight task and reducing ab initio training requirements. Agate has also been a strong supporter of HITS.

Researchers had previously found that with performance control, non-pilots could learn to fly a simulator in 15 min. Beringer tested the system in a simula-

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tor configured as a Piper Malibu at CAMI. It used HITS displays and a four-axis side-arm controller. Twenty-four individuals with varying flight experience participated: six high-flight-time pilots; six low-flight-time pilots; six student pilots, and six non-pilots. Each flight involved a takeoff into instrument conditions, a continuous climb while turning downwind, a turn to intercept the instrument landing system glidepath, and a descent to landing. Flights were divided between use of a conventional yoke and the side-arm controller.

The findings were consistent. The aircraft was more stable and had less variations in course and altitude using performance control than with conventional controls. Although experienced pilots

The **big innovation** is use of synthetic vision symbology

always outperformed less-experienced individuals, with either system, all agreed the effort required was nearly halved.

Performance control is not apt to be seen in Piper Cubs, but perhaps in Beech Bonanzas and Piper Malibus. A lot of them already have two- or three-axis autopilots, so a significant capability could be achieved by rigging a side-stick control to the autopilot, Beringer said.

But two large problems must be overcome for performance controls to appear in the next generation of GA aircraft. The first is cost. Affordable and certifiable computer controls and servos would have to drop to a level competitive with more conventional systems.

Second, a fly-by-wire debate must be resolved. Could an affordable system be built with sufficient reliability using triple- or quad-redundancy, or would a costly manual-reversion be required? A mechanical backup would add cost for installation and for training pilots to operate the two systems.

Complicating that issue is the question of the level of reliability required. The FAA's current standard for a flight-critical system is a failure rate of 10^{-9}. While this is a standard for NASA, it might not be reasonable for general aviation aircraft. Beringer points out that the failure rate for humans is about 10^{-3}.

04802

DOT/FAA/AM-02/7

Office of Aerospace Medicine
Washington, DC 20591

Applying Performance-Controlled Systems, Fuzzy Logic, and Fly-By-Wire Controls to General Aviation

Dennis B. Beringer
Civil Aerospace Medical Institute
Federal Aviation Administration
Oklahoma City, OK 73125

May 2002

Final Report

U.S. Department
of Transportation

**Federal Aviation
Administration**

NOTICE

Technical Report Documentation Page

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This work was performed under Task AM-A-00-HRR-519.

16. Abstract
A fuzzy-logic "performance control" system, providing envelope protection and direct command of airspeed, vertical velocity, and turn rate, was evaluated in a reconfigurable general aviation simulator (configured as a Piper Malibu) at the FAA Civil Aerospace Medical Institute. Performance of 24 individuals (6 each of high-time pilots, low-time pilots, student pilots, and nonpilots) was assessed during a flight task requiring participants to track a 3-D course, from take-off to landing, represented by a graphical pathway primary flight display. Baseline performance for each subject was also collected with a conventional control system. All participants operated each system with minimal explanation of its functioning and no training. Results indicated that the fuzzy-logic performance control reduced variable error and overshoots, required less time for novices to learn (as evidenced by time to achieve stable performance), required less effort to use (reduced control input activity), and was preferred by all groups.

17. Key Words	18. Distribution Statement
Fly-by-Wire Control, Performance-Controlled System, Flight Controls, Highway-in-the-Sky Display, Pathway Display, Pilot Training	Document is available to the public through the National Technical Information Service Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	14	

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04805

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04806

Applying Performance-Controlled Systems, Fuzzy Logic, and Fly-By-Wire Controls to General Aviation

BACKGROUND

In the opening of his book chapter titled *Pilot Control,* Sheldon Baron stated, "The importance of flight control to the development of aviation is difficult to overestimate" (Baron, 1988). Looking back through the history of aviation, we can see numerous efforts to make the human control of aircraft simpler, less variable, and more reliable. The 1970s was a particularly fertile period during which there was a great interest in efforts to simplify the manual control of systems, and one of those efforts was embodied in the "performance control system" (PCS) for aircraft (Bergman, 1976). This scheme allowed more direct control of performance parameters than did "conventional" systems and had the potential for eliminating undesirable aircraft behaviors and simplifying ab initio training. It is worth reiterating the history, as it still applies to general aviation (GA) aircraft, although some military and commercial air carrier aircraft employ what we could legitimately call performance-control logic.

The top-level goal for a flight is arrival at the destination. This can then be decomposed to sub goals, which involve the attainment of locations along the chosen path that can be used to assess progress toward the end goal. Progress toward these subgoals can then be directed by causing the aircraft to move toward those spatial subgoals, through manipulating ground track, altitude, etc. However, manual control of aircraft, using mechanical linkages in which control positions have a one-to-one correspondence with positions of the aerodynamic control surfaces, does not allow direct control of aircraft end-goal states. Rather, the pilot must effect changes in attitude and powerplant settings to cause changes in the higher-level performance variables. Turning to a specific heading, for example, requires the pilot to manipulate roll rate (aileron position) directly, to achieve a desired turn rate (indirectly), which will ultimately bring the aircraft to the desired heading. Mathematically, we have the pilot serving as at least a second-order integrator and, in some cases, a third-order integrator. (See Roscoe & Bergman, 1980; and Baron, 1988, for further discussion.)

A manual control task becomes easier to perform as its "order" approaches zero (Roscoe and Bergman, 1980), that is, when the human operator directly commands the end state of the system. We can achieve closer to a zero-order system in two ways. The most common means of accomplishing this in today's aviation environment is the autopilot in GA aircraft, or the Flight Management System (FMS) in corporate and scheduled carriers. In the simplest case of flying a heading, one sets the desired heading and the autopilot maneuvers the aircraft, at a specified limited rate of turn, to attain that heading. A second way in which we can achieve this result is to alter the control laws such that the pilot uses control position to command higher-level performance goals (for example, rate of turn/bank angle; rate of climb/descent), attaining a compromise between automated maneuvering and the authority inherent in manually guided maneuvering. There are two benefits that accrue from the latter approach. First, manual control is simplified relative to achieving performance-goal states. Second, safety is enhanced relative to conventional manual controls in that return of the self-centering (spring-loaded) side-stick to its centered position returns the aircraft to straight-and-level flight.

One should keep in mind that the gains seen with a PCS come at the expense of being unable to perform such maneuvers as barrel rolls and loops (requiring direct authority over control surfaces), which is not usually a problem in everyday GA flying. Recall that the PCS is commanding rate of climb and rate of heading change (via bank angle) directly, and thus any maneuver that would require a continuous non-zero pitch-change *rate* or bank-change *rate cannot be performed.* Previous research results from the GA environment using a PCS (Roscoe & Kraus, 1973; Bergman, 1976; Roscoe & Bergman, 1980) have indicated significant reductions in both mean and variable tracking error during the performance of navigation tasks, as well as a reduction in workload. These results were obtained both in a twin-engine simulator and in a conventionally instrumented Twin Bonanza with the PCS installed (controlled via a side-stick device), certified for normal flight operations with few procedural restrictions.

Stewart (1994) also examined, in a GA simulator, an implementation of a performance-control logic he termed the "E-Z Fly" control system for GA aircraft. Control was achieved through the normal control yoke, but the operator commanded vertical speed and rate of heading change. The throttle was used to command airspeed directly. The control logic contained limits on the commandable range of flight-performance parameters so that dangerous or unreasonable configurations could not be commanded by the operator. The control system was used in conjunction with a highway-in-the-sky-format (HITS) primary flight display, and gain of the controls was reduced on final approach to match the reduced width of the HITS pathway as it narrowed down to the runway width. Control forces were manipulated such that they were reduced to zero when the controls were moved to a new position and held there for more than a few seconds.

The results reported by Stewart were from 3 pilots and 7 non-pilots. Control of altitude, airspeed, and lateral error was better for both groups when the E-Z Fly system was engaged, and both groups exhibited less accurate path tracking during turns than during straight segments. Throttle-lever activity was reduced using the E-Z Fly system, and all of the participants preferred the E-Z Fly system over conventional controls.

Interest in applying simplified control schemes to GA aircraft reappeared with the government/industry Advanced General Aviation Transport Experiments (AGATE) program. Program goals included simplifying the flight task, reducing ab initio training requirements, and increasing the safety of flight. In the pursuit of these goals, an approach similar to the PCS was investigated in which a "fuzzy-logic" controller (FLC) was developed (Duerksen, 1996). Duerksen's goals were to create a "reusable" decoupled flight controller that could be directly installed on different airframes without the usual individual "tuning" associated with autopilot systems, and, with this fuzzy-logic system serving as an expert-systems supervisor, to provide control boundaries such as angle of attack and airspeed limits. Duerksen's efforts produced usable code that was then evaluated for its ability to control an aircraft by using simulation. The code was subsequently transported to the Advanced General Aviation Research Simulator (AGARS) at the FAA's Civil Aerospace Medical Institute (CAMI) for pilot performance evaluations.

METHOD

Subjects and Design

Twenty-four individuals (6 each of high-time pilots, low-time pilots, student pilots, and nonpilots) participated in the study. Each participant served as his/her own control, flying both the conventional yoke and the side-arm FLC so that control configuration was a within-subject variable. Each flight consisted of 9 discernable segments that were used as a second independent within-subject variable. Order of presentation of control type was counterbalanced across subjects. Dependent variables recorded included lateral and vertical course-tracking error (via digital recording), and control movements and blunder errors (via videotape).

Equipment

Data were collected in the AGARS configured as a Piper Malibu with a highway-in-the-sky format navigation display, using a follow-me airplane symbol and velocity vector on the copilot's side of the panel. The conventional system was flown with a back-loaded yoke and separate power controls. The FLC system was flown using 3 axes of a balanced, spring-centered and damped 4-axis side-arm controller (Figure 1; Beringer, 1999), with those axes representing turn rate (wrist rotation), climb / descent rate (vertical wrist flexion), and airspeed (fore-aft slide axis).

Procedures and Task

Following the signing of consent forms, participants were seated in the right seat of the AGARS for a short pre-flight briefing. The functioning and movement of the controller they were to use for that flight were described and demonstrated. Participants manipulated the side-arm control with their left hand, necessitated by structural restrictions on control and display placement, but were free to use either hand to manipulate the yoke. They were also shown the navigation display and given an explanation of its symbology and functioning. The simulator's engine was then started, and the flight was begun without any actual hands-on training in the use of the controls and displays. The experimenter, seated in the left seat, monitored the participant's progress and intervened only when it was necessary to limit extreme excursions of the simulator, to manipulate power in the conventional-controls configuration, or to prevent stalls or ground contacts. The pattern required a continuous climb from lift-off until the base-leg turn and then a descent on the approach.

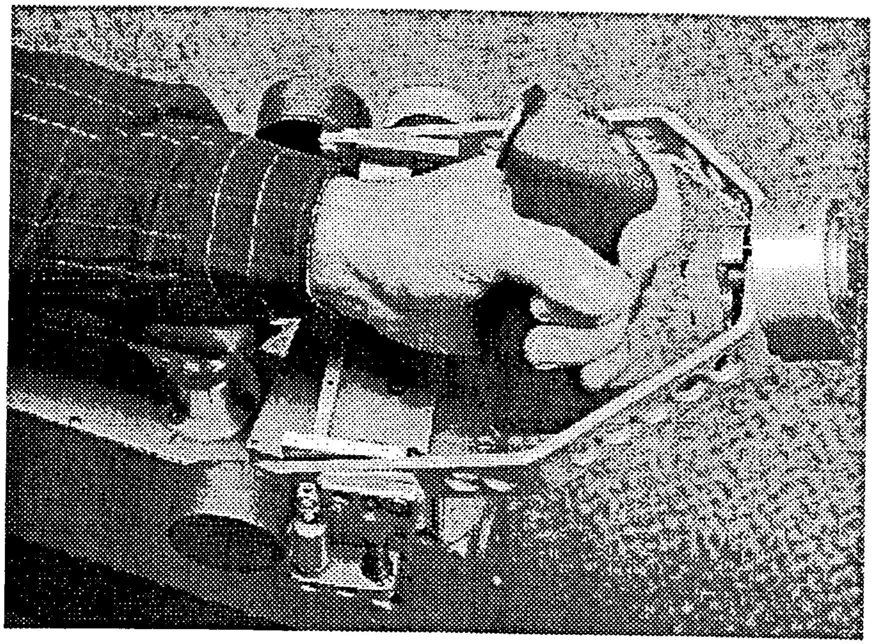

Figure 1. Four-axis side-arm controller used to implement the fuzzy-logic control inputs (Beringer, 1999).

The task required the participant to take off, establish a climb to intercept the pathway depicting the desired 3-D courseline, and follow the command guidance indicator (follow-me airplane) by aligning the aircraft velocity vector with the follow-me airplane. The subject was required to follow the command indications through a greatly extended pattern with a lengthened down-wind leg that turned back toward the airport (Albuquerque, runway 08) at the Albuquerque VOR and followed the instrument landing system (ILS) approach back to the runway. The flights ranged from 15 to 17 minutes. After a short break, the participant and experimenter discussed the functioning of the second controller to be used and performed a second flight with that controller. On both flights, the simulator entered actual instrument conditions on initial climbout and no external visual cues were available to the subject until breaking out just before landing. The session was concluded with post-test questionnaires about previous flight experience and about the participant's ratings of the 2 control systems.

RESULTS & DISCUSSION

Tracking Error

Analyses indicated that there were substantial reductions, as seen in the Bergman studies, in both mean and variable errors in the vertical and horizontal dimensions when the FLC was used, as compared with the conventional controller (yoke). Overall analyses by group and control type indicated that use of the FLC produced less error, both horizontally and vertically (Figure 2). There were significant reductions in root-mean-square error (RMSE) for both vertical [$F(1,40)= 18.11$, $p<0.0005$] and lateral [$F(1,40)=14.06$, $p<0.001$] and a shift in lateral bias (mean) error [$F(1,40)=21.09$, $p<0.00001$)] (overall bias was to the left of courseline).

Much of the error reduction came in the turns, and Figures 3 and 4 show raw data plots for one nonpilot over the complete course. One can see in Figure 3 that the performance with conventional controls was far more variable, with the aircraft repeatedly flying through its commanded altitude. Figure 4 shows the lateral-error plot, and it also contains greater departures from desired track (and more variability) for the conventional control than for the FLC. One can also see where turns 3 and 4 were overshot considerably. These performance differences between control systems were consistent across all 4 groups of subjects, although the high-time pilots and 2 of the student pilots tended to fly more precisely, regardless of the type of control system used. Analyses also revealed some intraserial transfer (as found by Bergman), in that the conventional system initially fared worse if preceded by the FLC than when the conventional system was flown first. This effect dissipated over flight segments, however. No such effect was apparent for the FLC system. Overall, time to achieve stable

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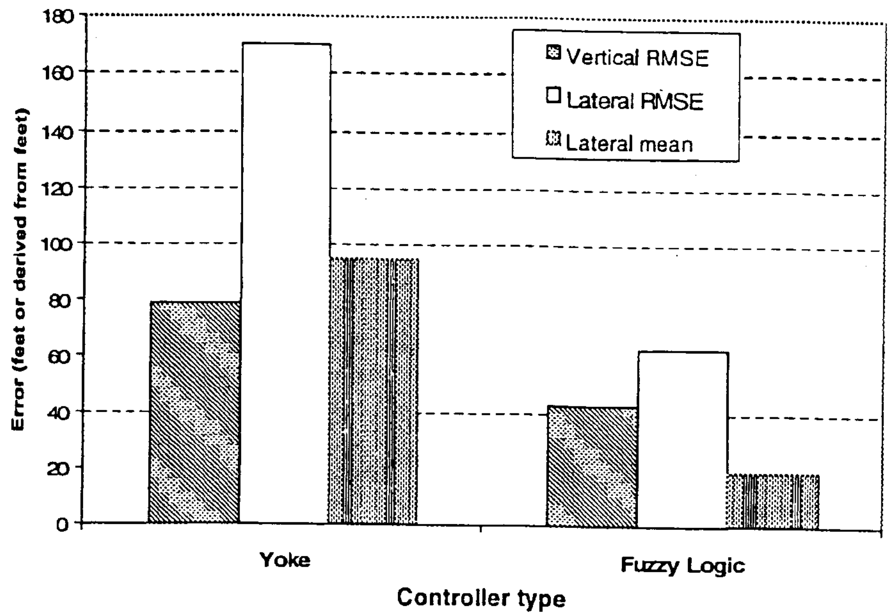

Figure 2. Main effects of control type for 3 measures of error.

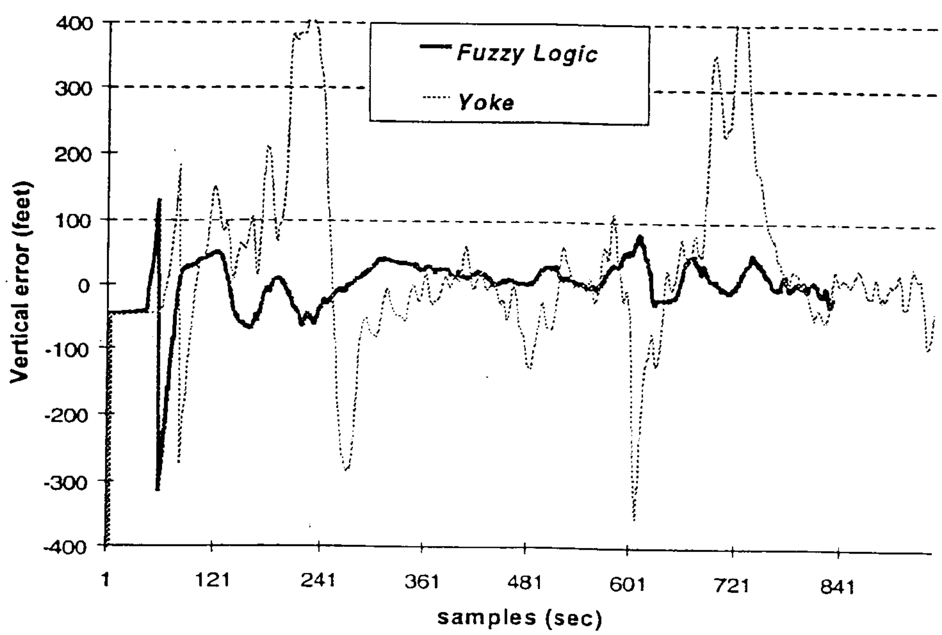

Figure 3. Plot of raw vertical error for 1 nonpilot.

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performance was less for the FLC than for the conventional system. (The large spike at the beginning of the record is an anomaly in path error calculation that occurred prior to path capture.)

There were also the expected significant differences between the pilot groups (Figure 5), with the high- and low-time pilots exhibiting somewhat less error (lateral and vertical RMSE) than the nonpilots and student pilots [$F(3,40)$ for each: vertical mean, $F=3.22$, $p<0.05$; vertical RMSE, $F=5.23$, $p<0.005$; lateral RMSE approached significance, $F=2.8$, $p=0.0518$]. Group means are presented in Figure 5. No interactions between control type and pilot group were significant.

Control-Input Frequency

One could predict from an analysis of required control motions that the FLC should produce at least a 2:1 reduction in the frequency of observed control movements. That is, to enter and hold a given bank angle, the yoke requires at least 2 deflections (one to initiate and 1 to neutralize aileron at the desired bank angle), whereas the FLC requires a single deflection to the position corresponding to the bank angle (turn rate). Table 1 depicts data for 4 individuals, 1 randomly selected from each group (non-pilot, student pilot, low-time pilot, high-time pilot), sampled for 30 seconds from Turn #1 (T1: crosswind leg), Turn #3 (T3: base leg), and final approach (App). With 2 exceptions in which the ratios are higher, the comparisons evidenced an approximately 3:1 reduction in control movements (defined as directional reversals) from the conventional control (Y) to the FLC (F). This measure can be thought of as an index of controlling workload, and the selected data shown are representative of the larger sample.

Participant Ratings

Participants rated each of the control systems for the degree of effort required during takeoff, climb, turns, level flight, descent/approach, and landing. The rating scale used 9 points from 1 (minimum effort) to 9 (maximum effort). Overall, the FLC was preferred over the conventional system (Figure 6), and participants rated the former as easier to use [$F(1,40)=34.73$, $p<0.00001$]. Those who were not pilots indicated that the FLC was easier to learn to use (Figure 6). Although there were some minor mean-rating differences between groups, pilot group was not a significant factor, nor was there a significant interaction between control type and pilot group.

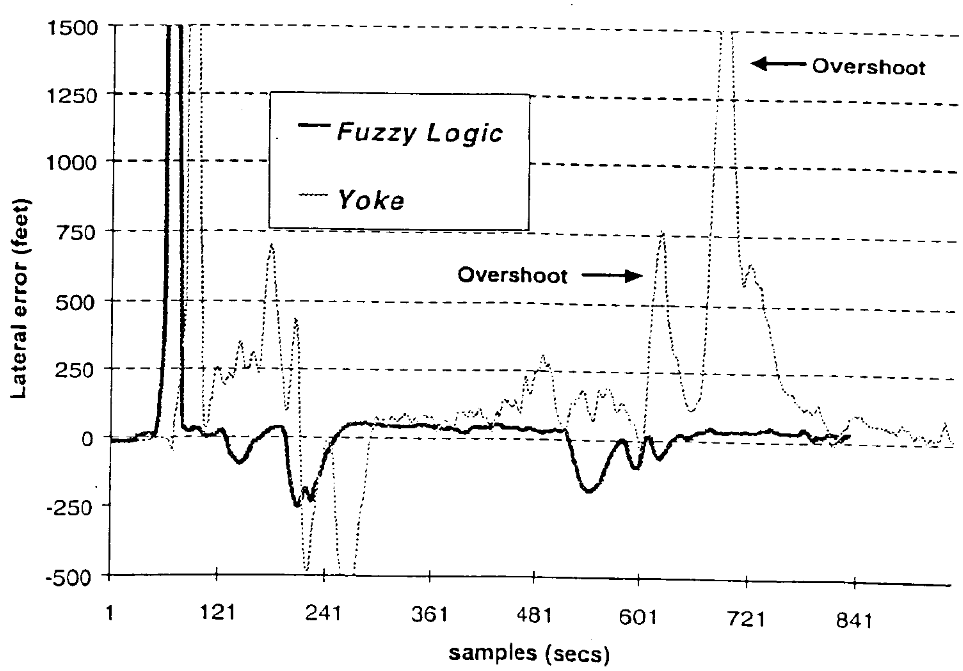

Figure 4. Plot of raw lateral error for 1 nonpilot.

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Table 1. Frequency of control inputs by maneuver for 4 individuals, 1 from each pilot group.

		Turn1		Turn 3		Approach		*Means*	
Pilot Type	***Control Axis***	Yoke	FLC	Yoke	FLC	Yoke	FLC	*Yoke*	*FLC*
Non	Pitch	na	na	10	0	4	5	*7.0*	*2.5*
	Roll	12	11	18	5	29	3	*19.6*	*6.3*
Stu	Roll	28	9	na	na	na	na	*28.0*	*9.0*
Low	Pitch	10	1	4	0	4	2	*6.0*	*1.0*
	Roll	24	12	20	7	24	5	*22.6*	*8.0*
High	Pitch	8	0	8	1	6	2	*7.3*	*1*
	Roll	11	4	16	6	10	2	*12*	*4*

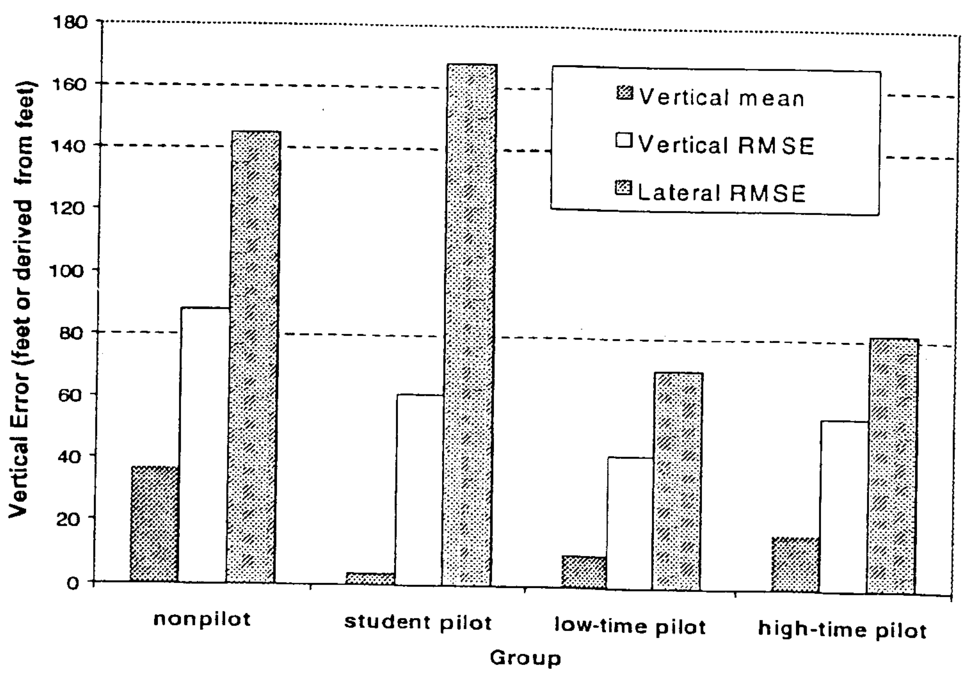

Figure 5. Three error measures by group.

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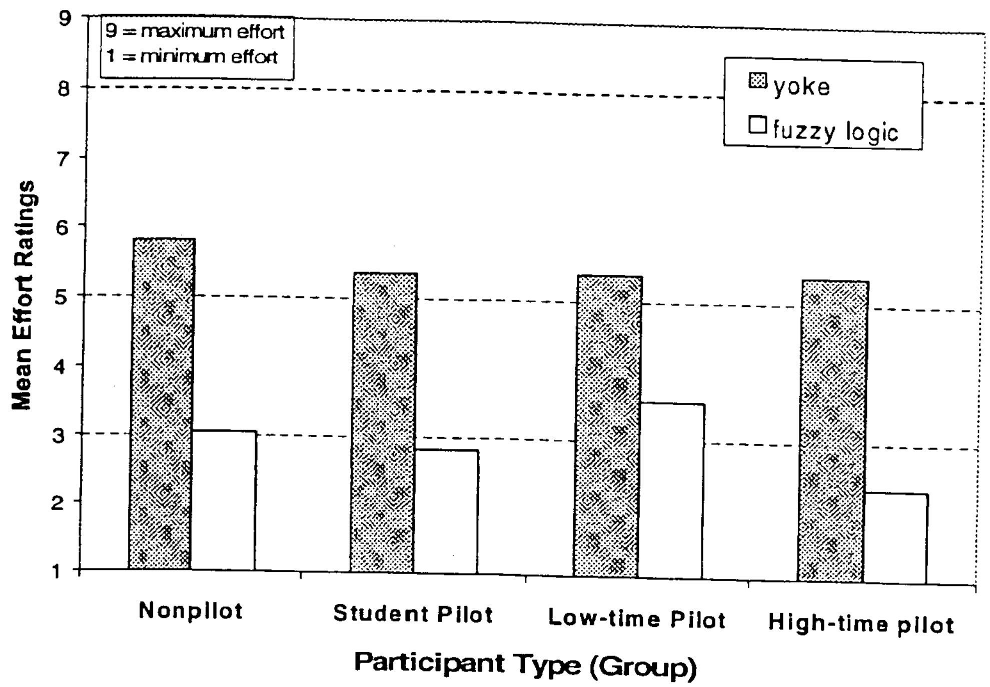

Figure 6. Mean perceived-effort ratings by group and control type.

When examined by flight segment, the biggest difference in ratings was found in the turns for all but low-time pilots. The one complaint with the FLC was the same as that in the Bergman studies. That is, users did not like having to hold the side-stick control deflected for long periods of time to maintain a climb or descent, although they rated it as "acceptable," due to a low spring force in that axis. This has since been addressed, and pilots can now "lock-in" desired performance and control position, thus alleviating the need to continually hold the control in the deflected position, coupled with a release mechanism triggered by force applied to the control.

Two additional observations are worth making regarding the results. First, there should not have been a significant effect of hand used for manipulating the FLC, in this case due to the low spring loading and comparatively low required input frequency. If there was an effect for the predominantly right-handed sample, then we are seeing the worst-possible case for this implementation. Second, the effect does not appear to be restricted to a specific display type, as earlier positive results (Bergman) were obtained with conventional instrumentation.

CONCLUSIONS

The findings were consistent with previous PCS studies, indicating that the FLC system can provide stable and less variable course and altitude tracking performance than a conventionally configured system when used as a manual control. This makes the system a potential alternative for next-generation GA aircraft from pilot-performance and pilot-training standpoints. However, there are 2 considerable concerns that must be addressed prior to application in a production aircraft. First, the cost of the system must come down to the point where it is an economic competitor with other means of aircraft control (meaning affordable and certifiable control computer, servos, etc.). Second, the debate must be resolved over reliability and reversion modes and their effect upon training. If the system is to be implemented in a class of aircraft where no other means of control will be available as a backup (only 1 type of control is trained), reliability must be sufficiently high. If, however, a reversion mode is provided to allow for a slightly less reliable FLC, then one either adds the cost of redundant identical systems, or one employs a stand-by mechanical linkage system and incurs the cost and complexity of training the pilot to operate *both* types of control systems. Again, it ultimately comes down to where one wishes to incur the cost for potentially increased safety and ease of operation.

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A disclosure under 37 CFR 1.56 must be in writing as prescribed by 37 CFR 1.2, and a copy of any such disclosure must be filed in each application or other proceeding to which the disclosure pertains (37 CFR 1.4(b)).

2003 Disclosure — When Made

In reissue applications, applicants are encouraged to file information disclosure statements at the time of filing or within 2 months of filing, since reissue applications are taken up "special" (see MPEP § 1442 and § 1442.03). However, in a reissue where waiver of the normal 2 month delay period of 37 CFR 1.176 is being requested (see MPEP § 1441), the statement should be filed at the time of filing the application, or as soon thereafter as possible.

The presumption of validity is generally strong when prior art was before and considered by the Office and weak when it was not. See *Bolkcom v. Carborundum Co.*, 523 F.2d 492, 498, 186 USPQ 466, 471 (6th Cir. 1975).

2003.01 Disclosure After Patent Is Granted

BY CITATIONS OF PRIOR ART UNDER 37 CFR 1.501

Where a patentee or any member of the public (including private persons, corporate entities, and government agencies) has prior patents or printed publications which the patentee or member of the public desires to have made of record in the patent file, patentee or such member of the public may file a citation of such prior art with the U.S. Patent and Trademark Office pursuant to 37 CFR 1.501. Such citations and papers will be entered without comment by the Office. The Office does not of course consider the citation and papers but merely places them of record in the patent file. Information which may be filed under 37 CFR 1.501 is limited to prior art patents and printed publications. Any citations which include items other than patents and printed publications will not be entered in the patent file. See MPEP § 2202 through § 2208.

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2004 Aids to Compliance With Duty of Disclosure

While it is not appropriate to attempt to set forth procedures by which attorneys, agents, and other individuals may ensure compliance with the duty of disclosure, the items listed below are offered as examples of possible procedures which could help avoid problems with the duty of disclosure. Though compliance with these procedures may not be required, they are presented as helpful suggestions for avoiding duty of disclosure problems.

04819

X-38 - Summary

The X-38 program was initiated to demonstrate the technologies required to develop a Crew Return Vehicle (CRV). The X-38 design effort was begun at Johnson Space Center in 1995 as an alternative to the Russian Soyuz capsule, which was too small for the Station's six person crew. The vehicle is being developed in-house by NASA at a fraction of the cost of past human space vehicles. The goal is to take advantage of Commercial Off-the-Shelf (COTS) technology for 80% of the vehicle to deliver four flight units for approximately $500 million.

The X-38 / CRV will be ferried to the International Space Station by the Space Shuttle where it will remain docked for up to two years and serve as a crew life boat in the event of an emergency. X-38 demonstration tests, which began in July 1997, should enable the procurement of an operational vehicle in late 1999.

The X-38 design uses a lifting body concept originally developed by the Air Force's X-24A project in the mid-1970's. After the de-orbit engine module is jettisoned, the X-38 would glide from orbit unpowered like the Space Shuttle and then use a steerable, parafoil parachute, a technology recently developed by the Army, for its final descent to landing. Its landing gear would consist of skids rather than wheels.

Currently, atmospheric drop tests are being conducted at Dryden Flight Research Center on three test vehicles. The drop tests will eventually increase in altitude to 50,000 feet and will include longer free-flight durations prior to parafoil deployment. An unpiloted space test vehicle is scheduled to be deployed from the Shuttle in 2000 to assess atmospheric re-entry performance and verify the full capabilities of the system. Assuming a satisfactory outcome, an operational system will be deployed in 2003.

Prime Contractor:	Johnson Spaceflight Center
Point of Contact:	NASA Dryden Flight Research Center Public Affairs Office Edwards, CA 93523 Tel: 661.258.3449 Fax: 661.258.3566
Launch Sites:	Kennedy Space Center (28.6 deg. N Latitude)
Web Links:	NASA X-38 Web Site

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Web Links: NASA X-38 Web Site

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Facts

National Aeronautics and Space Administration

Dryden Flight Research Center - PO Box 273 - Edwards, California 93523 - (661) 276-3449

X-38

PLEASE NOTE: The X-38 program has been cancelled. For additional information, plea: contact NASA Headquarters Public Affairs Officer Dwayne Brown at 202-358-1726.

Project Background

The X-38 project is a series of five prototype research vehicles developing technology to build and operate a space station crew return vehicle (CRV). The wingless CRV, when operational, would be the first reusable human spacecraft to be built in more than two decades.

Three X-38s are serving as testbeds in the development program and NASA Dryden Flight Research Center, Edwards, Calif., is the site of the program's atmospheric flight-testing. A fourth vehicle will be space-rated and used to evaluate the CRV design when it is released from an orbiting space shuttle to return to Earth.

The design of the X-38 incorporates the wingless lifting body concept pioneered at Dryden. Six unique lifting body configurations were tested at Dryden between 1963 and 1975. Data from th aerodynamic studies contributed to the design and operational profile of the space shuttles and reemerging to help develop the CRV.

When operational, the CRV will be an emergency vehicle to return up to seven International Space Station (ISS) crewmembers to Earth. It will be carried to the space station in the cargo bay of a space shuttle and attached to a docking port. If an emergency arose that forced the IS crew to leave the space station, the CRV would be undocked and - after a deorbit engine burn - the vehicle would return to Earth much like a space shuttle. The vehicle's life support system w have a duration of about seven hours. A steerable parafoil parachute would be deployed at an altitude of about 40,000 feet to carry it through the final descent and the landing. The CRV is being designed to fly automatically from orbit to landing using onboard navigation and flight control systems. Backup systems will allow the crew to pick a landing site and steer the parafoi to a landing, if necessary.

NASA's Johnson Space Center, Houston, Texas, manages the X-38 program and works with personnel from Dryden Flight Research Center, and Langley Research Center, Hampton, Va.

The Vehicles

The X-38 design closely resembles the X-24A lifting body flown at Dryden from April 1969 to 1971. Wingless lifting bodies generate aerodynamic lift - essential to flight in the atmosphere - from the shape of their bodies.

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The 28 research missions flown by the X-24A helped demonstrate that hypersonic vehicles like the space shuttle returning from orbital flight could be landed on conventional runways without power. The X-24A was modified in 1970 and designated the X-24B in 1971, the last lifting body configuration was tested in the 12-year research program at Dryden.

The three prototype X-38s used in the atmospheric flight testing program are 24.5 feet long, 11.6 feet wide, and 8.4 feet high, approximately 80 percent of the planned size of the CRV. The prototypes are designated V131, V132, and V131R. The V131 prototype was modified for additional testing beginning in the summer of 2000 and now carries the designation V131R. A fourth prototype, V133, will incorporate the exact shape and size of the planned CRV.

The atmospheric test vehicles, built by Scaled Composites, Mojave, Calif., are shells made of composite materials such as fiberglass and graphite epoxy, and strengthened with steel and aluminum at stress points. Vehicle weights range from 15,000 pounds to about 25,000 pounds. They land on skids - reminiscent of the famed X-15 research aircraft - instead of wheels.

The fourth X-38 in the program will be V201, the space-rated vehicle that will be flown back to Earth from an orbiting space shuttle. NASA is constructing it at the Johnson Space Center. Its inner compartment, representing the crew area, will be a pressurized aluminum chamber. A composite fuselage structure will enclose the chamber and the exterior surfaces will be covered with a Thermal Protection System (TPS) to withstand the heat generated by air friction as the vehicle returns to Earth through the atmosphere. The TPS will be similar to materials used on tl space shuttles, but much more durable - carbon and metallic-silica tiles for the hottest regions, and flexible blanket-like material for areas receiving less heat during atmospheric reentry.

Much of the technology being used in the X-38 is off-the-shelf, but that doesn't mean it is old or out-dated.

The flight control computer and the flight software operating system are commercially developed and used in many aerospace applications. The space-flig X-38 prototypes will have newly designed actuators

The current electro-mechanical actuators that move the vehicle's flight control surfaces for pitch, yaw, a roll control have been used on earlier NASA, Air Force, and Navy aeronautical research projects.

Inertial navigation and global positioning systems, similar to units used on aircraft throughout the worl will be linked to the vehicle's flight control system t automatically steer the vehicles along the correct reentry path during atmospheric tests and during th space flight test.

Using global positioning already programmed into tl navigation system, the flight control computer becomes the autopilot that flies the vehicle to a predetermined landing site.

The U.S. Army originally developed the design of the parafoil that deploys in the atmosphere ar carries the X-38 to Earth. The shroud lines of the steerable parachute are attached to risers linked to actuators controlled by the flight control system. The flight control system receives inputs from the inertial navigation and global positioning units to determine where the vehicle i and steers the parachute until it gets to its destination. During the descending flight, the direction and speed of any winds are calculated by the flight control system and steerage corrections are automatically made. The parafoil guidance system also predicts wind direction across the landing zone and automatically turns the vehicle up wind for a safe landing.

During atmospheric tests at Dryden, the X-38s are dropped from the wing pylon of NASA's B-5: launch aircraft at altitudes ranging from 25,000 feet to 45,000 feet. The higher altitudes give engineers more time to study vehicle aerodynamics and handling qualities during its controlled, unpiloted gliding descent before the steerable parachute is deployed.

GenCorp Aerojet, Sacramento, Calif., is developing the propulsion unit that will be used during the X-38 de-orbit tests. After the X-38 is released from the shuttle cargo bay, the small aft-mounted deorbit rocket will be fired to slow the vehicle's speed to let gravity begin pulling it back to Earth. The rocket unit will be jettisoned during the descent phase. The same deorbit propulsion unit will more than likely be used on CRVs operating with the International Space Station.

A Flush Air Data Sensing System (FADS) developed at Dryden is being used on the X-38 to collect vehicle air speed and attitude (pitch and yaw) data. This information is fed into the flight control computer to maintain the desired flight path. FADS uses tiny ports to collect the aerodynamic data instead of using conventional probes that extend into the air stream. FADS data is also monitored by test personnel on the ground during test flights.

A bank of storage batteries will provide electrical power on each of the X-38 test vehicles to operate the avionics, navigation, guidance, flight control, and parachute steering systems.

The X-38 that will be test flown from the space shuttle and the future CRV itself will use nitroge gas attitude control systems for guidance and control during flight in space where conventional control surfaces are ineffective.

X-38 Test and Development Schedule

X-38 flight-testing began in March 1998 with Vehicle 131 and it will continue atmospheric testir with Vehicle 133 through 2004 or 2005.

Vehicle 131 was taken aloft by the B-52 launch aircraft for several captive-carry flights beginnir in July 1997 to study its aerodynamics while attached to the aircraft's wing pylon. Two brief fre flights followed, in March 1998 and February 1999, to study launch characteristics and to asses the operation of the parachute, from deployment of the small drogue through reefing of the ma parafoil and landing. Data from the two flights have helped improve drogue deployment and lec to landing skid improvements.

Following the two flights, Vehicle 131 was returned to Scaled Composites to be modified into th actual shape of the future CRV. The vehicle, now designated V131R, has been delivered to the Johnson Space Center where navigation, guidance, flight control, and parachute deployment systems are being installed. The modified vehicle will have the aerodynamics and atmospheric flight capabilities of the full-size CRV in the summer of 2000 when a series of up to six atmospheric test flights is scheduled to begin.

Vehicle 132, which also has the bulbous X-24A shape, carries a full flight control system, including electro-mechanical control surface actuators similar to those to be used on the CRV. V132 was test flown in March and July of 1999 with its final flight on March 30, 2000. It was the highest, fastest and longest flight to date.

The primary objectives of the flights are testing and validating the parachute deployment and steering systems, along with the vehicle's automatic flight control system.

Atmospheric test vehicle 133 is representative of the size and shape of the planned CRV. It will be used to fully test the spacecraft's integrated avionics, guidance, and flight control systems, while studying the vehicle's aerodynamics, handling qualities, and the reliability of the parachut and its steering system.

The Dryden Connection

The connection between Dryden and the X-38 prototypes begins with the lifting body program (the 1960s and 70s, from which the CRV concept emerged. It now encompasses engineers involved in flight test planning and technicians working on the design and integration of vehicle systems. Dryden personnel help operate and staff mission control centers during test flights, ar provide expertise in the areas of flight research, aerodynamics, and flight-control systems.

The concept of using a parafoil to autonomously recover a spacecraft from orbit and make a precision landing was successfully tested at Dryden between October 1991 and December 1996 in a project called the Spacecraft Autoland. In 1995, this concept was extended to flying a one-sixth scale X-38 using a small parafoil.

Precursors to actual X-38 flights were made to evaluate vehicle control under the parafoil using four-foot model of the vehicle. The instrumented test article was carried into the air and droppe 13 times from a Cessna U-206 at California City, Calif., near Dryden.

One of the most prominent components of X-38 support is the B-52 launch aircraft used to take the X-38 to drop altitude. The aircraft, older than any B-52 still flying, is the same launch aircra used in the X-15 program and was the so-called "mother ship" for all lifting bodies in that nine-year research program. The aircraft has been reconfigured to support a variety of crewed and uncrewed research vehicles that needed to be carried aloft to begin their flights back to the dry lake or conventional runways of Edwards Air Force Base.

The electro-mechanical actuators that move the flight control surfaces on the X-38s are a product of aeronautical research at Dryden. They were developed as space and weight-savers f all-electric flight control systems on new aircraft.

Dryden's involvement with the X-38s also extends to the personnel who have helped develop th flight software that will be used on V201, and its vehicle's guidance, flight control, and flight termination systems.

Pre- and post-flight vehicle inspections are conducted by a team of Dryden maintenance and engineering specialists accustomed to working with unconventional crewed and uncrewed research vehicles.

Through the entire X-38 planning and development program, Dryden engineers and technicians have served as consultants in a variety of disciplines. These include vehicle handling and flying qualities, guidance and control systems, test planning, and analyzing the flight test data.

Project History and Participants

X-38 three view.

The X-38 project began at the Johnson Space Cent in early 1995 using data from past lifting-body programs and the U.S. Army's Guided Precision Delivery System tests from Yuma Proving Grounds Yuma, Ariz. Flight tests began in Yuma using pallet dropped from an aircraft to study and develop the steerable parafoil system.

In early 1996, a contract was awarded to Scaled Composites for the construction of two atmospheric test vehicles. The first vehicle, V131, was delivered to the Johnson Space Center in September 1996, where it was outfitted with avionics, computer systems, and other hardware in preparation for its initial flight tests at Dryden. The second vehicle wa delivered to JSC in December 1996.

In October 1998, Scaled Composites received an additional contract to modify V131 into V131R.

GenCorp Aerojet, Sacramento, Calif., is designing and building a de-orbit propulsion unit that w be used on V201. The base contract, valued at $16.4 million, is for one propulsion stage for the V201 flight test, with an option for a second unit. There is a second option in the contract for fi operational flight units if the project is approved and the operational CRVs are built. All options would have a potential value of $71.9 million.

Total projected cost to develop and flight test the X-38s is approximately $700 million. Using available technology and off-the-shelf equipment has significantly reduced project costs, when compared to other space vehicle projects. Original estimates to build a capsule-type CRV were more than $2 billion in total development cost.

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About 100 people, mostly civil servants, are currently working on the X-38 project at the

About 100 people, mostly civil servants, are currently working on the X-38 project at the Johnson, Dryden, and Langley centers. The X-38 project is the first in which a prototype space vehicle has been built-up in-house by NASA at the Johnson Space Center, rather than by a contractor. This approach has advantages. By building the vehicles in-house, NASA engineers have a better understanding of the problems contractors experience when they build vehicles fc NASA.

The agency's X-38 team will have a detailed set of requirements for the contractor to use when the operational CRVs are built. This type of hands-on work dates back to the National Advisory Committee for Aeronautics (NACA), predecessor agency of NASA.

The Future

Once CRVs are operational at the International Space Station, modified follow-on versions of th vehicles could be used for brief science missions after being placed in orbit by Space Shuttles o expendable booster rockets such as the American Delta series and the French Ariane.

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PAO Webmasters

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United States Patent [19]

Margolin

[11] **Patent Number:** **5,904,724**

[45] **Date of Patent:** **May 18, 1999**

[54] **METHOD AND APPARATUS FOR REMOTELY PILOTING AN AIRCRAFT**

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

[21] Appl. No.: **08/587,731**

[22] Filed: **Jan. 19, 1996**

[51] **Int. Cl.**[6] **G06F 165/00**; H04N 7/18

[52] **U.S. Cl.** **701/120**; 701/2; 701/24; 244/189; 244/190; 348/114

[58] **Field of Search** 364/423.099, 424.012, 364/424.013, 424.021, 424.022, 449.2, 449.7, 460, 439, 424.028; 340/825.69, 825.72, 967, 989, 991, 992, 993; 244/189, 190, 181, 17.13, 3.11, 3.15; 348/42, 51, 113, 114, 117, 123, 143; 382/154; 395/118, 119, 125

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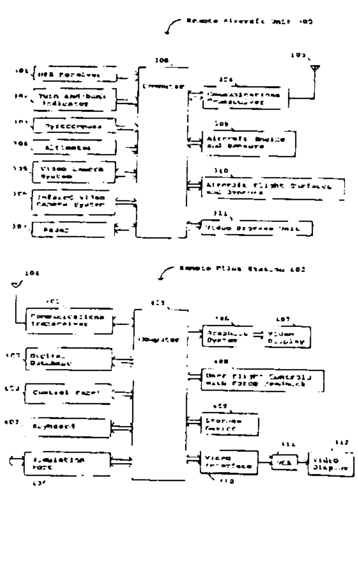
Primary Examiner—Tan Q. Nguyen

Attorney, Agent, or Firm—Blakely, Sokoloff, Taylor and Zafman LLP

[57] **ABSTRACT**

A method and apparatus that allows a remote aircraft to be controlled by a remotely located pilot who is presented with a synthesized three-dimensional projected view representing the environment around the remote aircraft. According to one aspect of the invention, a remote aircraft transmits its three-dimensional position and orientation to a remote pilot station. The remote pilot station applies this information to a digital database containing a three dimensional description of the environment around the remote aircraft to present the remote pilot with a three dimensional projected view of this environment. The remote pilot reacts to this view and interacts with the pilot controls, whose signals are transmitted back to the remote aircraft. In addition, the system compensates for the communications delay between the remote aircraft and the remote pilot station by controlling the sensitivity of the pilot controls.

20 Claims, 7 Drawing Sheets



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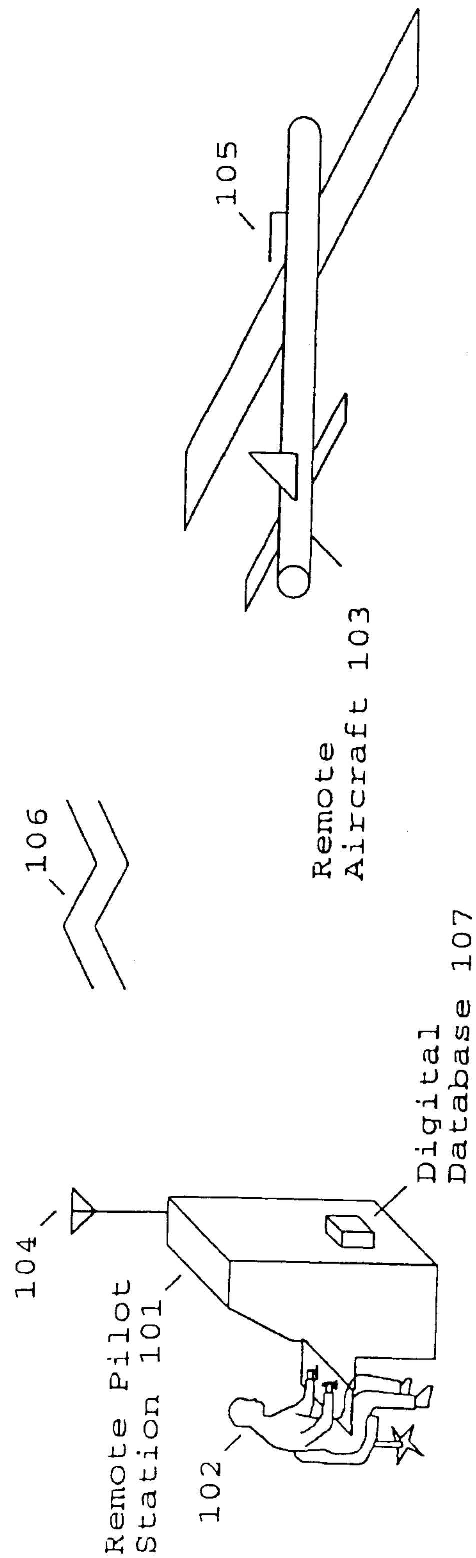
105
Remote Aircraft 103
106
Digital Database 107
104
Remote Pilot Station 101
102

Fig. 1

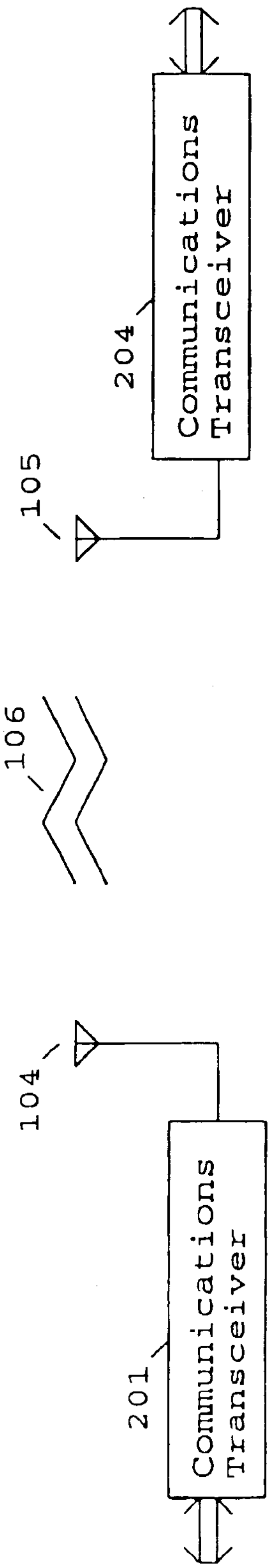
Communications Transceiver
204
105
106
104
Communications Transceiver
201

Fig. 2

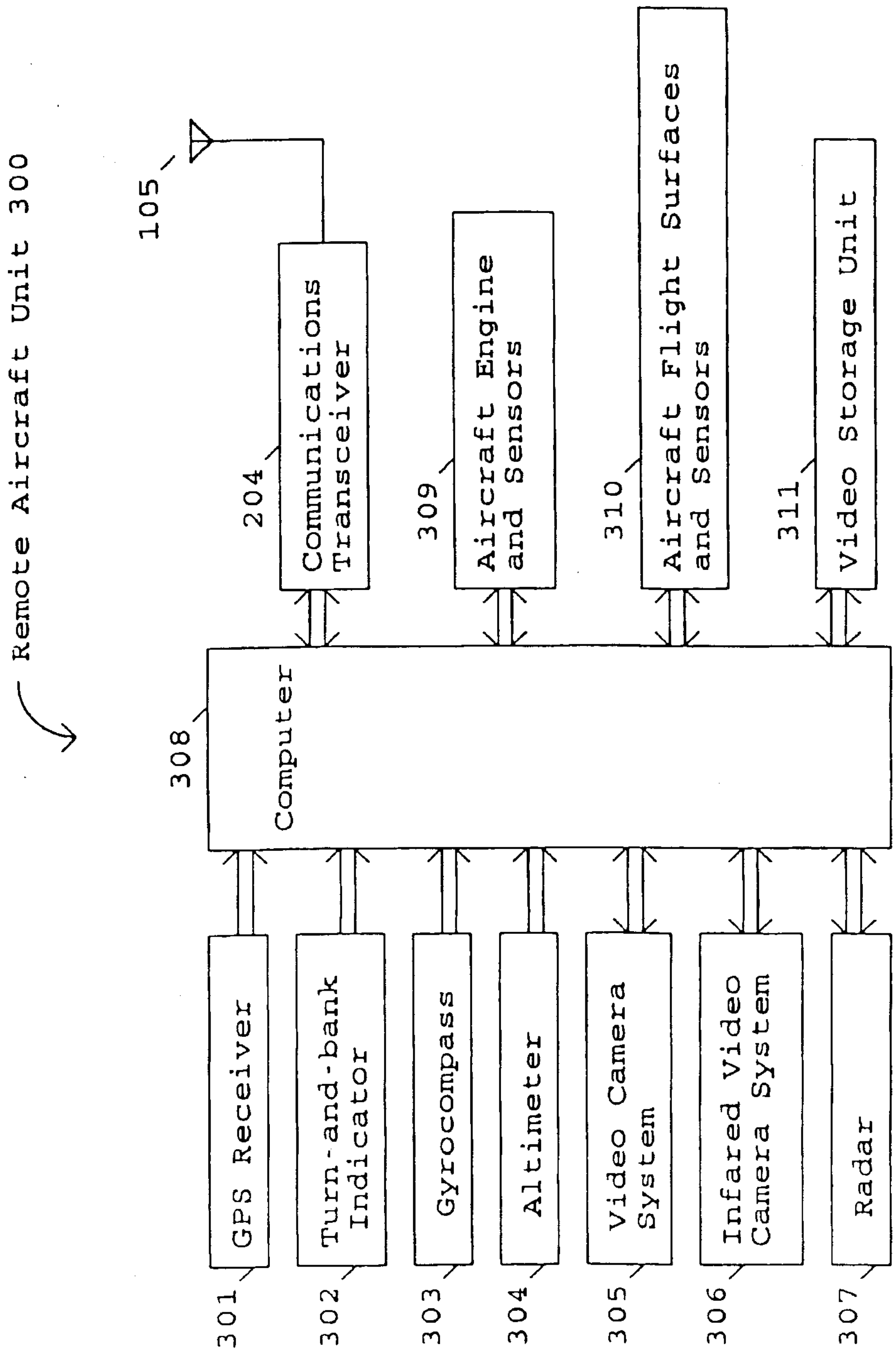
Remote Aircraft Unit 300
105
204
Communications Transceiver
309
Aircraft Engine and Sensors
310
Aircraft Flight Surfaces and Sensors
311
Video Storage Unit
308
Computer
GPS Receiver
Turn-and-bank Indicator
Gyrocompass
Altimeter
Video Camera System
Infared Video Camera System
Radar
301
302
303
304
305
306
307

Fig. 3

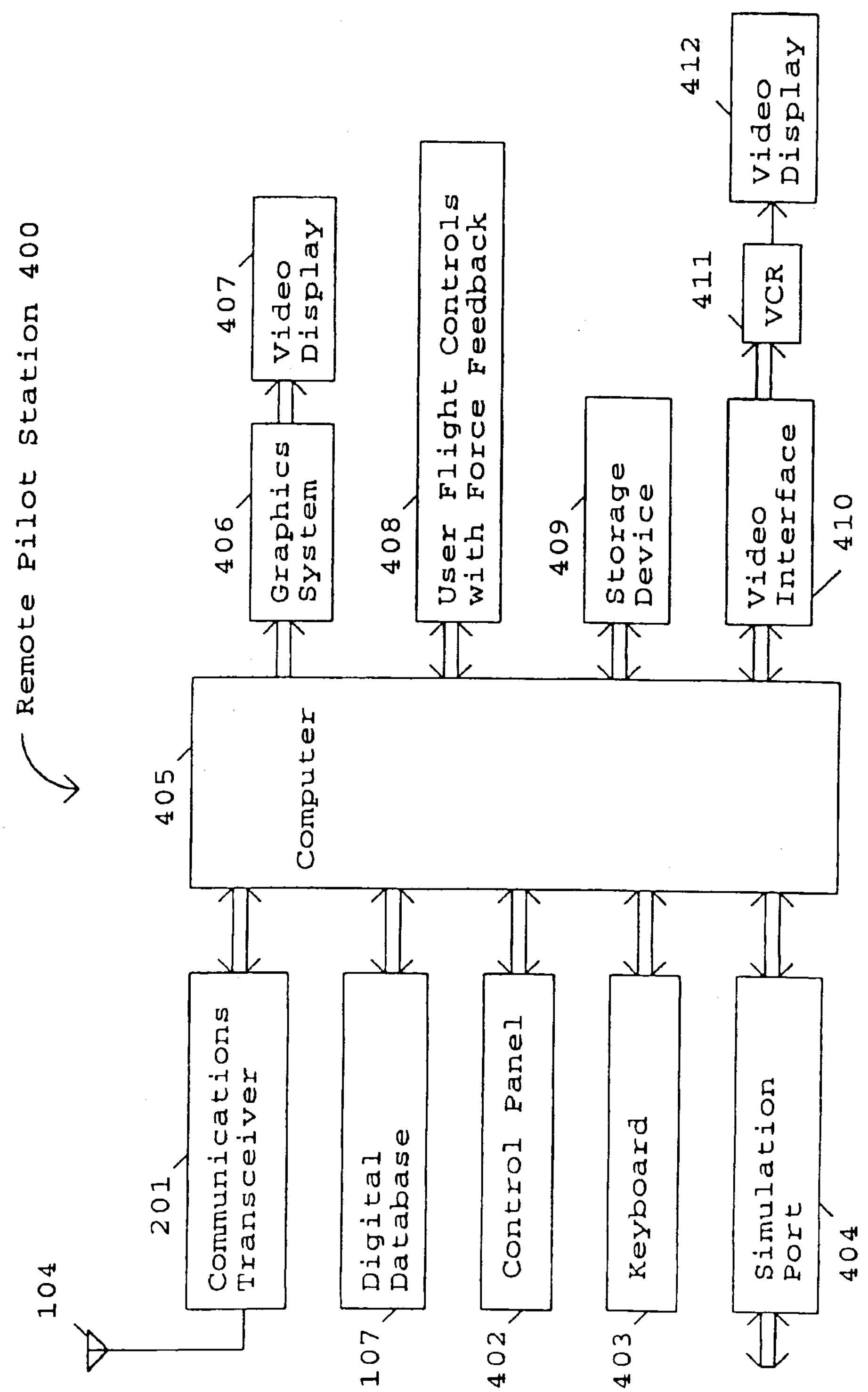
Remote Pilot Station 400
104
201
Communications Transceiver
107
Digital Database
402
Control Panel
403
Keyboard
404
Simulation Port
405
Computer
406
Graphics System
407
Video Display
408
User Flight Controls with Force Feedback
409
Storage Device
410
Video Interface
411
VCR
412
Video Display

Fig. 4

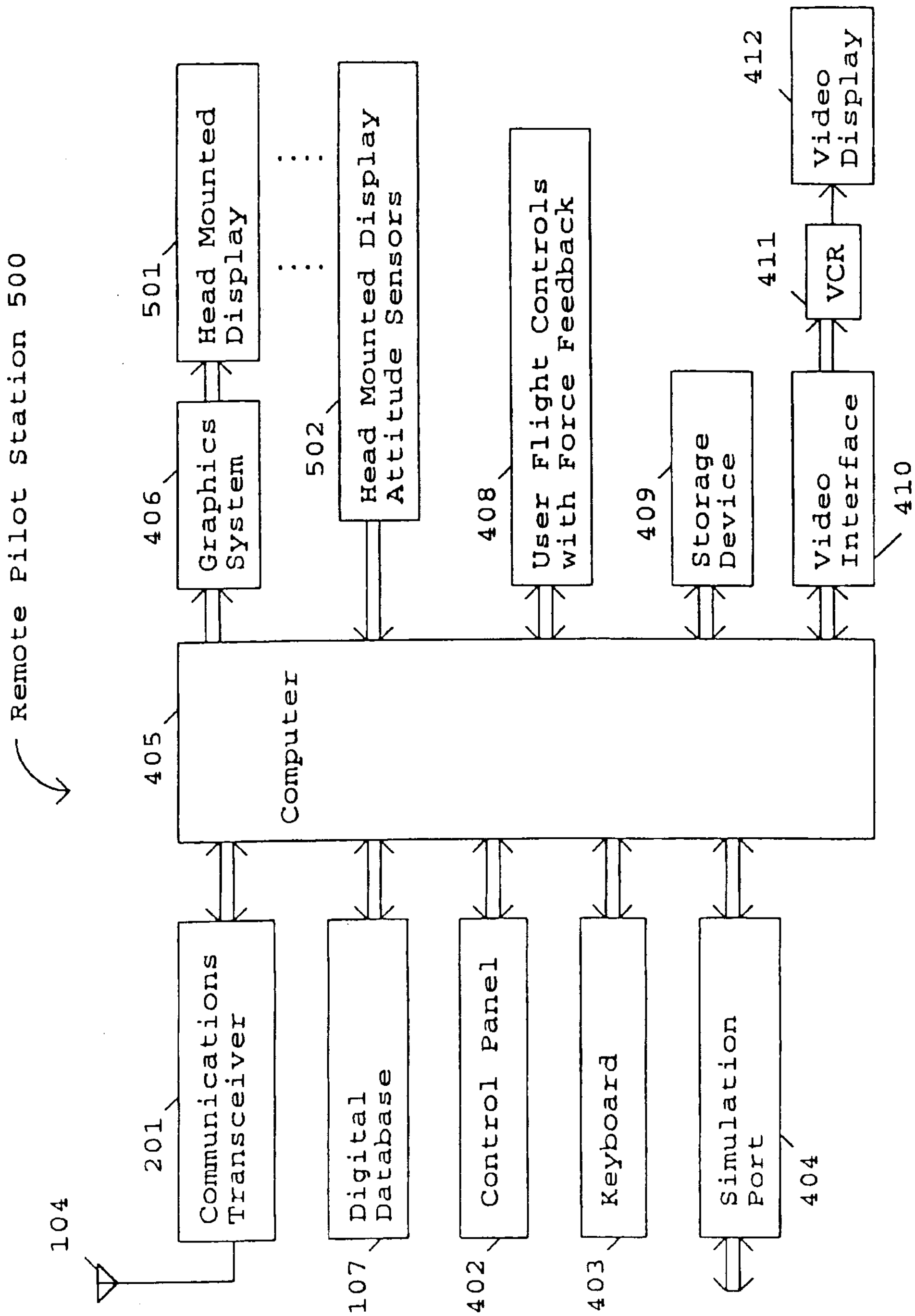
Remote Pilot Station 500
104
201
Communications Transceiver
107
Digital Database
402
Control Panel
403
Keyboard
404
Simulation Port
405
Computer
406
Graphics System
501
Head Mounted Display
502
Head Mounted Display Attitude Sensors
408
User Flight Controls with Force Feedback
409
Storage Device
410
Video Interface
411
VCR
412
Video Display

Fig. 5

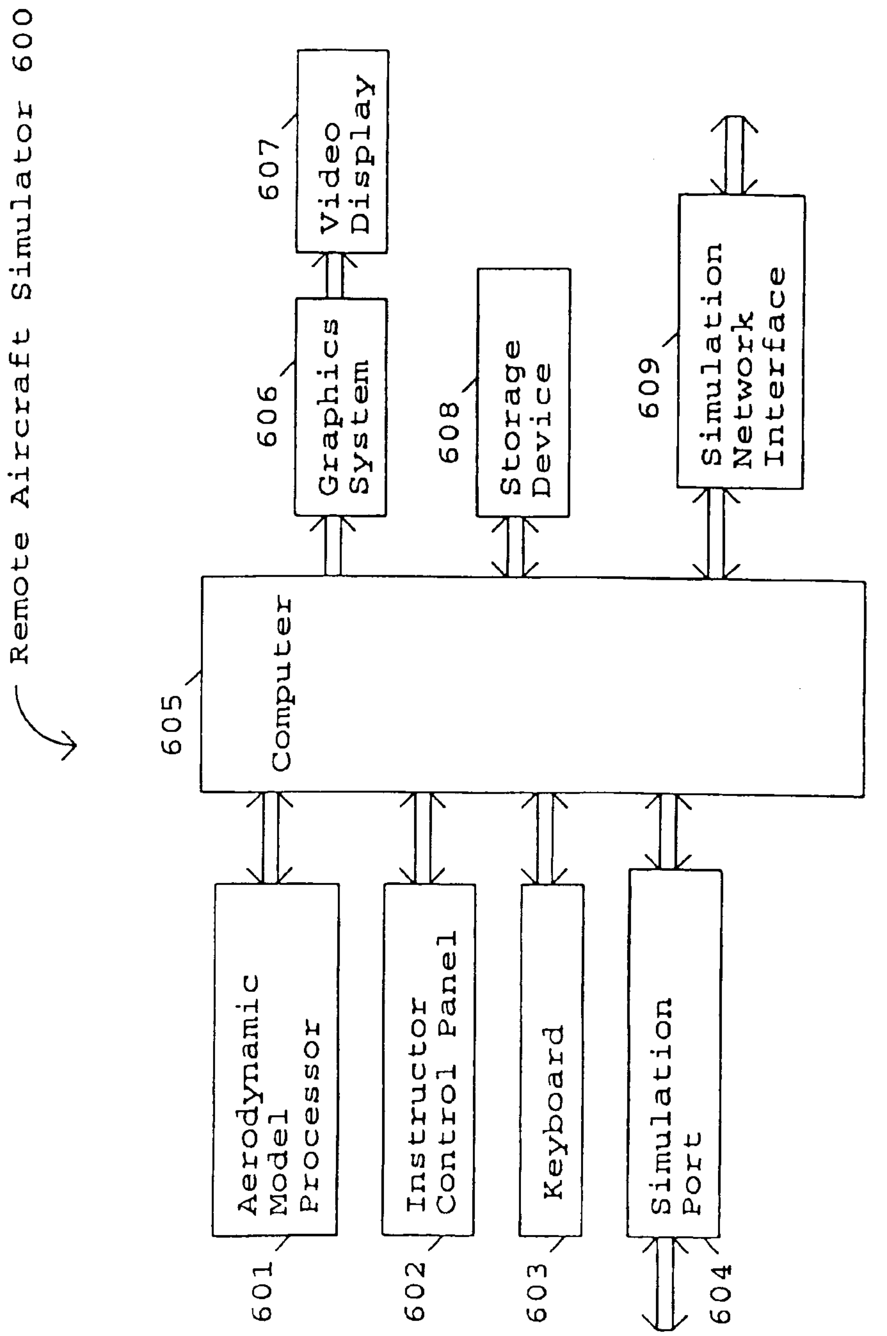
Remote Aircraft Simulator 600
605
Computer
606
Graphics System
607
Video Display
608
Storage Device
609
Simulation Network Interface
601
Aerodynamic Model Processor
602
Instructor Control Panel
603
Keyboard
604
Simulation Port

Fig. 6

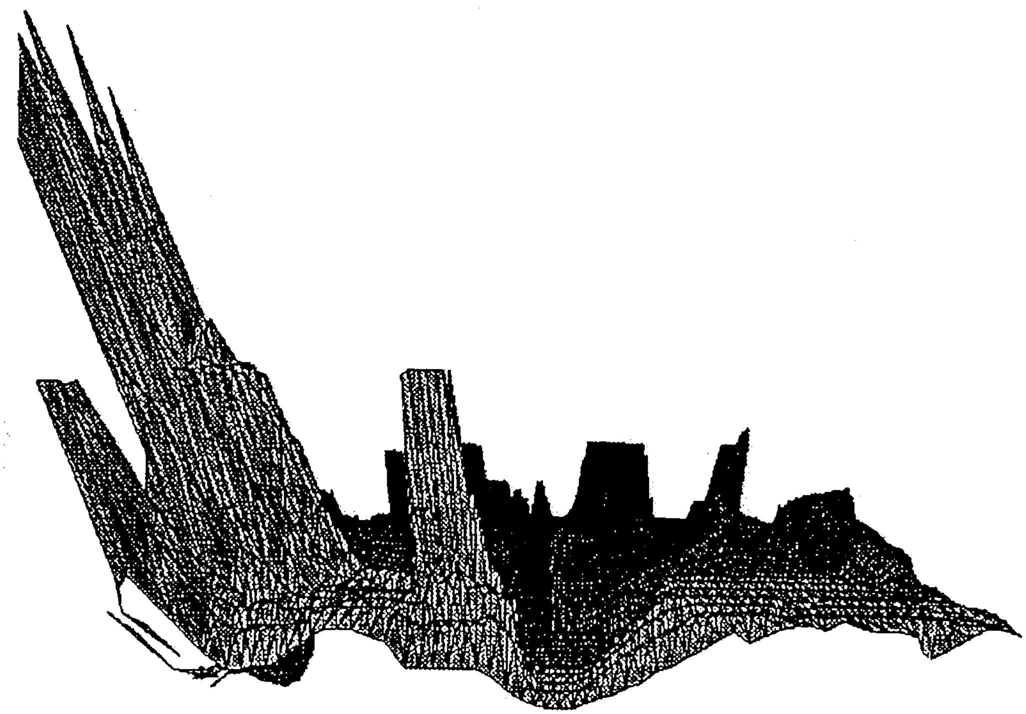

Figure 7

METHOD AND APPARATUS FOR REMOTELY PILOTING AN AIRCRAFT

BACKGROUND OF THE INVENTION—CROSS REFERENCES TO RELATED APPLICATIONS

"Pilot Aid Using a Synthetic Environment", Ser. No. 08/274,394 filed Jul. 11, 1994. "Digital Map Generator and Display System", Ser. No. 08/543,590, filed Oct. 16, 1995.

1. Field of Invention

This invention relates to the field of remotely piloted vehicles (RPVs) and unmanned aerial vehicles (UAVs).

2. Discussion of Prior Art

RPVs can be used for any number of purposes. For example, there is a large organization that promotes the use of remote controlled planes. Certain RPVs are controlled by viewing the plane with the naked eye and using a hand held controller to control its flight Other RPVs are controlled by a remote pilot using simple joysticks while watching the video produced by a camera in the remote aircraft. This camera is also used to produce the reconnaissance video. There are tradeoffs involving the resolution of the video, the rate at which the video is updated, and the bandwidth needed to transmit it. The wider the bandwidth the more difficult it is to secure the signal. The freedom to balance these tradeoffs is limited because this video is also used to pilot the aircraft and must therefore be updated frequently.

Certain UAVs are preprogrammed to follow a predetermined course and lack the flexibility to deal with unexpected situations.

The 1983 patent to Kanaly (U.S. Pat. No. 4,405,943) shows a control and communications system for a remotely piloted vehicle where an oculometer determines where the remote operator is looking and signals the remote vehicle to send the high resolution imagery corresponding to the area around where the remote operator is looking and low resolution imagery corresponding to the remote operator's peripheral vision. The objective is to minimize the bandwidth of the information transmitted to the remote operator.

SUMMARY

A method and apparatus is described that allows a remote aircraft to be controlled by a remotely located pilot who is presented with a synthesized three-dimensional projected view representing the environment around the remote aircraft According to one aspect of the invention, a system is used that includes an aircraft and a remote pilot station.

The aircraft uses a communications link to send its location, attitude, and other operating conditions to the remote pilot station. The remote pilot station receives the data and uses a database describing the terrain and manmade structures in the remote aircraffs environment to produce a 3D view of the remote aircraft environment and present it to the remote human pilot.

The remote pilot responds to the information and manipulates the remote flight controls, whose positions and forces are transmitted to the remote aircraft. Since the amount of data is small, it can be readily secured through encryption and spreadspectrum techniques.

Also, because the video reconnaissance cameras are no longer needed to remotely pilot the aircraft there is great flexibility in their use. To minimize bandwidth and reduce the possibility of being detected, the video data can be sent at a slow update rate. The data can also be stored on the remote aircraft for later transmission. Alternatively, low resolution pictures can be sent in real-time, while the corresponding high resolution pictures can be at a later time. The reconnaissance video can even be transmitted through a different communications link than the control data. There may also be more than one reconnaissance camera.

The delay in the control link must be minimized in order that the remote aircraft can be properly flown. The system can measure the link delay and make this information available to the pilot. This delay link measurement can also be used to modify the control software through which the remote pilot flies the remote aircraft. This is to prevent pilot-induced-oscillation.

The computers in the system allow for several modes of operation. For example, the remote aircraft can be instructed to fly to given coordinates without further input from the remote pilot. It also makes it possible to provide computer assistance to the remote pilot. In this mode, the remote flight control controls absolute pitch and roll angles instead pitch and roll rates which is the normal mode for aircraft In addition, adverse yaw can be automatically corrected so that the resulting control laws make the remote aircraft extremely easy to fly. Because this comes at the expense of being able to put the remote aircraft into unusual attitudes, for complete control of the remote aircraft a standard control mode is provided to give the remote pilot the same type of control that is used to fly a manned aircraft. Since the remote aircraft is unmanned, the remote pilot can subject the remote aircraft to high-G maneuvers that would not be safe for a pilot present in the aircraft.

To facilitate training, a simulated remote aircraft is provided that allows an instructor to set up the training mission and parameters. This is especially useful in giving remote pilots experience flying with different control link delays. In this simulated mode, the system can be further linked to a battlefield simulator such as SIMNET.

In the first embodiment, the remote pilot is provided with a standard video display. Additional display channels can be provided to give the remote pilot a greater field of view. There can even be a display channel to give a rearward facing view.

A second embodiment uses a head mounted display for the remote pilot instead of a standard display. This permits the remote station to be made more compact so that it can be used in a wider variety of installations. An example would be in a manned aircraft flying several hundred miles away.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may best be understood by referring to the following description and accompanying drawings which illustrate the invention. In the drawings:

FIG. 1 is a general illustration showing a remote pilot at a remote pilot station operating a remote aircraft according to one embodiment of the invention.

FIG. 2 is a block diagram showing the communications link between a remote pilot station and a remote aircraft according to one embodiment of the invention.

FIG. 3 is a block diagram of a remote aircraft according to one embodiment of the invention.

FIG. 4 is a block diagram of a remote pilot station according to one embodiment of the invention.

FIG. 5 is a block diagram of a remote pilot station according to another embodiment of the invention.

FIG. 6 is a block diagram of a remote aircraft simulator used for training remote pilots according to one embodiment of the invention.

FIG. 7 is an example of a three dimensional projected image presented to a remote pilot by a remote pilot station according to one embodiment of the invention.

DETAILED DESCRIPTION

In the following description, numerous specific details are set forth to provide a thorough understanding of the invention. However, it is understood that the invention may be practiced without these specific details. In other instances, well-known circuits, structures and techniques have not been shown in detail in order not to obscure the invention.

A method and apparatus is described that allows a remote aircraft to be controlled by a remotely located pilot who is presented with a synthesized three-dimensional projected view representing the environment around the remote aircraft. Since the video from a reconnaissance camera located on the remote aircraft is not used to pilot the remote aircraft, the amount of data transmitted between the remote aircraft and the remote pilot is small. This provides greater flexibility in how the remote aircraft is used and allows the transmitted data to be made more secure. The remote aircraft may be of any type, for example a remote control plane or helicopter as used by recreational enthusiast.

FIG. 1 is a general illustration showing a remote pilot at a remote pilot station operating a remote aircraft according to one embodiment of the invention. FIG. 1 shows Remote Pilot 102 interacting with Remote Pilot Station 101 and controlling Remote Aircraft 103. Remote Pilot Station 101 and Remote Aircraft 103 respectively include an Antenna 104 and an Antenna 105 for communicating Information 106.

In one embodiment, Information 106 includes status information concerning the status of Remote Aircraft 103 and flight control information for controlling the flight of Remote Aircraft 103. The status information is generated by Remote Aircraft 103 and includes the three dimensional position and the orientation (also termed attitude, and comprising heading, roll, pitch) of Remote Aircraft 103. The status information may also include information concerning the flight surfaces, the engine, an additional altitude reading, etc. Remote Pilot Station 101 uses this status information to retrieve data from a Digital Database 107 which contains a three-dimensional description of terrain and manmade structures over which Remote Aircraft 103 is flying. Based on the three dimensional data retrieved from Digital Database 107, Remote Pilot Station 101 projects a synthesized three-dimensional projected view of the terrain and manmade structures in the vicinity of Remote Aircraft 103. Based on this view of the terrain and manmade structures, the Remote Pilot Station 101, on its own and/or in response to input from Remote Pilot 102, generates and transmits flight control information to Remote Aircraft 103 which adjusts its flight accordingly.

In one embodiment, the Remote Aircraft 103 is a remote controlled plane or helicopter used for recreational purposes. Since remote controlled planes and helicopters tend to be small in size, the circuitry in such remote aircraft to generate and receive Information 106 is minimized. In such systems, the Remote Pilot Station 101 may be implemented by including additional attachments to an existing portable computer. This allows the user to easily transport the remote aircraft and pilot station to an appropriate location for flight.

FIG. 2 is a block diagram showing a bi-directional communications link between a remote pilot station and a remote aircraft according to one embodiment of the invention. FIG. 2 shows Communications Transceiver 201 coupled to Antenna 104 of Remote Pilot Station 101, as well as Communications Transceiver 204 coupled to Antenna 105 of Remote Aircraft 103. In addition, FIG. 2 shows Information 106 being communicated between Antenna 104 and Antenna 105.

FIG. 3 is a block diagram of a remote aircraft unit used in the remote aircraft according to one embodiment of the invention. FIG. 3 shows Remote Aircraft Unit 300 including Computer 308 coupled to GPS Receiver 301, Turn-and-bank Indicator 302, Gyrocompass 303, Communications Transceiver 204, Aircraft Engine and Sensors 309, and Aircraft Flight Surfaces and Sensors 310. GPS Receiver 301 receives signals from the satellites that make up the global positioning system (GPS) and calculates the aircraft's position in three dimensions. Turn-and-bank Indicator 302 and Gyrocompass 303 provide the aircraft's orientation which comprises heading, roll, and pitch. This data is sent to Computer 308 for transformation into the previously described status information. Computer 308 transmits this status information to Communications Transceiver 204 which produces a radio signal and supplies it to Antenna 105.

The Aircraft Engine and Sensors 309 are coupled to control the aircraft's engine, while the Aircraft Flight Surfaces and Sensors 310 are coupled to control the aircraft's flight surfaces. The flight control information is received from the remote pilot station by Computer 308 through Antenna 105 and Communications Transceiver 204. This flight control information is processed by Computer 308 into the necessary signals for transmission to Aircraft Engine and Sensors 309 and Aircraft Flight Surfaces and Sensors 310 to control the aircraft's engine and flight surfaces, respectively. The operation of the aircraft's flight control surfaces will be later described with reference to FIG. 4.

In order to protect against ECM, the communications link between the Remote Pilot Station 101 and the Remote Aircraft 103 may be secured. While any number of different techniques may be used to secure this link, in one embodiment Computer 308 is implemented to encrypttdecrypt the data transmitted and Communications Transceiver 204 is implemented to use spread spectrum techniques.

Computer 308 may optionally be coupled to Altimeter 304, Video Camera System 305, Infrared Video Camera System 306, Radar 307, and/or Video Storage Unit 311. Altimeter 304 provides an output of the aircraft's altitude as a safety check in the event GPS Receiver 301 malfunctions. Thus, this additional altitude reading may also be transmitted to Remote Pilot Station 101 as part of the status information.

Video Camera System 305 is controlled by Computer 308 which determines where the camera is pointing as well as focusing and the zoom factor. The video produced by the camera is not used by the remote pilot for flying the remote aircraft, so there is more flexibility in using the video. As a result, any number of techniques can be used for receiving the images captured by Video Camera System 305. As examples:

1. High resolution, high update images may be sent back in real-time through the Communications Link, when the high bandwidth needed can be tolerated.
2. High resolution, low update images may be sent back in real-time through the Communications Link to reduce the bandwidth.
3. The video may be recorded in Video Storage Unit 311 for later transmission.
4. The video may be transmitted through a separate communications link.
5. There may be multiple video cameras.

Infrared Video Camera System 306 is similar to Video Camera System 305 and has the same operating modes.

Radar 307 in Remote Aircraft 103 may be passive or active. It may scan a particular pattern or it may track a selected object. Radar **307** may consist of several Radar units. The information from Radar **307** is processed by Computer **308** so that only the desired information is transmitted over the communication link to the Remote Pilot Station **101** for display.

FIG. 4 is a block diagram of a remote pilot station according to one embodiment of the invention. FIG. 4 shows a Remote Pilot Station **400** including a Computer **405** coupled to Communications Transceiver **201**, Digital Database **107**, Graphics System **406**, User Flight Controls with Force Feedback **408**, and a Storage Device **409**. The Storage Device **409** represents one or more mechanisms for storing data. For example, the Storage Device **409** may include read only memory TROM), random access memory (RAM), magnetic disk storage mediums, optical storage mediums, flash memory devices, and/or other machine-readable mediums. Of course, Digital Database **107** may be stored in one or more machine-readable mediums and/or in Storage Device **409**.

As previously described, Antenna **104** receives the radio signals transmitted by Remote Aircraft **103** representing the status information of Remote Aircraft **103**. These radio signals are transformed by Communications Transceiver **201** and sent to Computer **405**. Communications Transceiver **201** is set to the same mode as Communications Transceiver **204**, so that if, for example, spread spectrum techniques are used, the signal will be transparently received. Computer **405** recovers the data (de-encrypting, if required) so that the data communications from Computer **308** in the Remote Aircraft to Computer **405** in the Remote Pilot Station is transparent. Thus, the bi-directional communications link comprises the combination of Communications Transceiver **201**, Antenna **104**, Antenna **105**, and Communications Transceiver **204**.

As previously described, the status information received by Computer **405** includes the three dimensional position and the orientation of Remote Aircraft **103**. The status information may also include information concerning the flight surfaces, flight sensors, the engine, an additional altitude reading, etc. Computer **405** uses this status information to retrieve data from Digital Database **107** which contains a three-dimensional description of terrain and manmade structures over which Remote Aircraft **103** is flying. The composition and creation of the Digital Database **107** is further described later. Based on the three dimensional data retrieved from Digital Database **107**, Computer **405** performs the mathematical operations to transform and project the three dimensional data to generate video data representing a synthesized three-dimensional projected view of the terrain (and, if desired, manmade structures) in the vicinity or environment of Remote Aircraft **103**. This video data is transmitted to Graphics System **406**, which displays the synthesized three-dimensional projected view on Video Display **407**.

Since the image is generated from the digital database, virtually any image of the environment of the Remote Aircraft **103** can be generated. As examples, the pilot may select the environment to be: 1) a simulated image of what would be seen out of the cockpit of a manned aircraft on a similar flight path; 3) a simulated image of what would be seen when looking in any direction (e.g., backwards, out a side window, etc.); 3) a simulated image of what would be seen if a camera were tailing the remotely piloted aircraft; etc. In addition, the simulated image may be set to any magnification. Thus, the phrase environment of Remote Aircraft **103** is intended to include any image generated with reference to the remote aircraft's position.

The User Flight controls with Force Feedback **408** are used by the remote pilot to input flight path information. The User Flight Controls may be of any number of different types, some of which are further described later herein. The status information received by Computer **405** also includes information received from Aircraft Flight Surfaces and Sensors **310**. This information is used to actuate force feedback circuitry in User Flight Controls With Force Feedback **408**. Remote Pilot **102** observes the synthesized three-dimensional environment displayed on Video Display **407**, feels the forces on User Flight Controls With Force Feedback **408** and moves the controls accordingly. This flight control information is sent through the communications link, to Computer **308**, and is used to control the aircraft flight surfaces in Aircraft Flight Surfaces and Sensors **310**. Remote Pilot **102** also receives data from Aircraft Engine and Sensors **309** through the communications link and is able to send data back to control the engine.

Flight Control

To illustrate the operation of the remote aircraft, a fixed-wing airplane will be described as an example. However, the basic principles apply to other types of aircraft as well. The basic control surfaces of an airplane consist of the ailerons, the horizontal elevators, and the rudder. The ailerons are moved differentially (one up, one down) to rotate the airplane around its roll axis; the horizontal elevators cause the airplane to rotate around its pitch axis; and the rudder causes the airplane to rotate around its yaw axis.

When the ailerons are used to modify the lift characteristics of the wings, one wing creates more lift while the other wing creates less lift. This also changes the drag characteristics of the wings and results in a yaw force that is opposite to the yaw force that results from the tail section causing the airplane to weather-cock into the relative wind. It is this yaw force caused by the airplane weather-cocking into the relative wind that causes a banked airplane to turn. The opposite yaw force produced by using the ailerons is called adverse yaw; the rudder control is used to counteract this force to produce a coordinated turn.

The simplest type of flight control consists of a joystick and a set of rudder pedals. The controls are directly connected to the flight control surfaces. With a joystick, moving the stick left and right moves the ailerons, while moving the stick forward and backward moves the horizontal elevators. The rudder is controlled by two foot pedals, one for each foot, that are mounted on a common shaft and hinged in the middle like a seesaw. Pressing one foot pedal forward causes the other foot pedal to move backward and causes the rudder to also move in one direction. Pressing the other foot pedal causes it to move forward and the opposite pedal to move backward and causes the rudder to move in the opposite direction.

An alternative to the joystick is the control yoke which consists of a wheel attached to a shaft that moves in and out of the control housing. Turning the wheel clockwise or counterclockwise moves the ailerons; moving the wheel shaft in and out moves the horizontal elevators. The rudder pedals as the same as those used with a joystick.

In order to aid in a description of remote aircraft operation, it is thought worthwhile to first describe the operation of non-remotely piloted vehicles. Non-remotely piloted vehicles can be operated in one of two ways (also termed as flight control modes); direct control or computer control (also termed as computer mediated).

Direct Control Non-Remotely Piloted Vehicles

When the flight controls are connected directly to the control surfaces the result is a second order system. Using

the joystick as an example, moving the joystick left or right establishes a roll rate. The airplane continues to roll until the joystick is returned to the center position, after which the airplane remains in the bank angle thus established. The foot pedals are used to counteract the adverse yaw as previously described. Moving the joystick forward or backward establishes a pitch rate. The airplane continues to pitch until the joystick is returned to the center position, after which the airplane remains in the pitch angle thus established. Both the roll rate and the pitch rate are subject to the limits of the airplane's design.

Since the joystick is directly connected to the control surfaces, the aerodynamic forces on the control surfaces are transmitted back to the pilot, giving him or her valuable feedback on how the airplane is flying.

The successful operation of the second order system with the pilot in the loop depends on several factors such as the area and placement of the control surfaces, how much the control surfaces move in response to the movement of the pilot controls, and how long the airplane takes to respond to changes of the control surfaces. The total system characteristics also depend on the reaction time of the pilot. If the resulting system is poorly designed it may be unstable, which means it may not be possible for a human pilot to fly it safely. An example of an unstable system is where the pilot desires to perform a gentle roll to the right and so moves the joystick to the right, the airplane's roll rate is faster than the pilot desires so he/she attempts to compensate by moving the joystick to the left, the airplane rolls left at a rate that is faster than the pilot desires so he/she moves the joystick to the right, and so on, with the pilot constantly overcorrecting and with the aircraft's rolling motions constantly getting larger and larger until the aircraft gets into a condition from which it may not be possible to recover, (e.g., spinning into the ground). The type of loss of control described is usually referred to as 'pilot induced oscillation' and although it may be caused by an inexperienced or inattentive pilot, it is more often caused by poor airplane design. Therefore, new airplane designs are extensively tested to make sure they can be safely flown. Examples of airplanes that use direct control of the control surfaces (Direct Control Second Order Systems) are the Cessna 150 and the Piper Cub.

Computer Mediated Non-Remotely Piloted Vehicles

Computer mediated control systems use a computer between the pilot controls and the control surfaces. The pilot controls are read by the computer, the data are modified in a particular way, and the computer sends control signals to the control surfaces. The computer may also sense the forces on the control surface and use it to control force feedback to the pilot controls. This type of computer mediated control may be used to fly an airplane that would otherwise be unstable, such as the F16 or the F117. Aircraft such as the F16 and F117 are also second order systems because the position of the pilot's joystick represents rate of rotation.

There are risks inherent in a computer mediated system. Although the program can be simulated extensively before using it in an actual airplane, the computer program may be quite large and therefore difficult to simulate under all possible conditions. An example of this is the Swedish JAS 39 Gripen Fighter. Despite extensive simulation of the flight control system, during a test flight a Gripen crashed due to " . . . the flight control system's high amplification of stick commands combined with the pilot's" large, rapid stick movements"." The pilot had entered a low-speed high-banked turn at a 280 meter altitude with lit afterburners and was leaving the turn when his actions led to 'pilot-induced oscillation'. (Aviation Week & Space Technology, Aug. 23, 1993, pages 72–73).

Having described techniques for operating non-remotely piloted vehicles, the Fight Control Modes for RPVs will be described.

Second Order RPV Flight Control Mode

A second order control system for an RPV is inherently computer mediated because the remote pilot must interact through two computers: the computer in the remote aircraft and the computer in the remote pilot station.

Flying an RPV is further complicated because there are additional time delays in the loop. The computer in the remote aircraft must first determine the aircraft's position and orientation. The additional processing for transmitting a secure signal by encryption and/or spread spectrum techniques may create additional delays. Transmission delay of signals between the remote aircraft and remote pilot station is negligible for a direct path. However, if the signals are relayed through other facilities the delay time may be appreciable, especially if an orbiting satellite is used. There are additional delays in the remote pilot station as the remote aircraft's position and orientation are used to transform the data from the digital database to present the pilot with the synthesized 3D projected view from the remote aircraft. In one embodiment, the RPV system measures the various delays and modifies the control laws used by the computer in the remote pilot aircraft and in the feedback provided by the computer in the remote pilot station to the remote pilot. For example, the computer may adjust the sensitivity of the User Flight Controls **408** according to the delay (e.g., as the delay increases, the computer will decrease the sensitivity of the flight controls). The system also displays the measured delay to the remote pilot.

First Order RPV Flight Control Mode

The stability of the flight control system, and thus the flyability of an RPV, can be improved considerably by using a first order system. In one embodiment of such a first order system the position of the remote pilot's joystick represents an angle relative to the horizon, instead of representing a rate of rotation as in a second order system. The position of the joystick is transmitted to the computer in the remote aircraft which moves the control surfaces as required to place the remote aircraft in the requested orientation. The control system in the remote aircraft is still a second order system but the delays in the communications link and the remote pilot station are no longer a part of the system's loop.

When a joystick is centered, the remote aircraft will fly straight and level. When the joystick is to the right of center the remote aircraft will be in a right banked turn. When the joystick is to the left of center the remote aircraft will be in a left banked turn. When the joystick is backward from center the remote aircraft will be in a pitch up orientation. When the joystick is forward of center the remote aircraft will be in a pitch down orientation.

The amount of bank and pitch permitted depends on the design of the remote aircraft. A high performance remote aircraft will be capable of a greater amount of pitch and bank than will a low performance remote aircraft.

Referring again to FIG. **4**, Computer **405** may optionally be coupled to Control Panel **402**, Keyboard **403**, Simulation Port **404**, Video Interface **410**, VCR **411**, and/or Video Display **412**. In one embodiment, Control Panel **402** contains specialized lights, displays, and switches to allow a quicker response to situations than can be provided by Keyboard **403**. Control Panel **402** can be arranged to approximate the look and feel of an actual aircraft cockpit. Keyboard **403** allows the remote pilot to select various operating modes. For training purposes, Simulation Port **404** allows the remote pilot station to be connected to a remote aircraft simulator instead of an actual remote aircraft. The remote aircraft simulator will be further described with reference to FIG. 6. Storage Device **409** allows the flight data to be recorded. During playback this previously recorded data is substituted for real-time data from the remote aircraft to replay the mission for analysis. Any video received from any reconnaissance cameras on the Remote Aircraft **103** is converted by Video Interface **410** so that it can be recorded on VCR **411** and displayed on Video Display **412**. VCR **411** can also operate in straight-through mode so that the reconnaissance video can be viewed in real time.

FIG. **5** is a block diagram of a remote pilot station according to another embodiment of the invention. FIG. **5** shows Remote Pilot Station **500**. Remote Pilot Station **500** is similar to Remote Pilot Station **400** of FIG. 4, except Video Display **407** is replaced by Head Mounted Display **501**. In addition, Head Mounted Display Attitude Sensors **502** are coupled to Computer **405**. Head Mounted Display Attitude Sensors **502** measure the attitude of Head Mounted Display **501**. This information is used by Computer **405** to produce an additional three dimensional transformation of the data from Digital Database **107** to account for the attitude of the remote pilots Head Mounted Display **501**. This does not require any additional data from the remote aircraft. Of course, alternative embodiments could include both a video display and a head mounted display.

FIG. **6** is a block diagram of a simulated remote aircraft used for training remote pilots according to one embodiment of the invention. FIG. **6** shows Remote Aircraft Simulator **600** including Computer **605** coupled to Aerodynamic Model Processor **601**, Instructor Control Panel **602**, Keyboard **603**, Simulation Port **604**, Graphics System **606**, Storage Device **608**, and Simulation Network Interface **609**. Remote Aircraft Simulator **600** communicates with Remote Pilot Station **400** or **500** through Simulation Port **604**. Aerodynamic Model Processor **601** executes a mathematical model that simulates the behavior of a remote aircraft. An instructor uses Instructor Control Panel **602** and Keyboard **603** to select various training scenarios. Graphics System **606** and Video Display **607** are used to observe the operation of the system. Storage Device **608** is used to record the training session for later evaluation of the session. In addition to proficiency training, the Remote Aircraft Simulator can also be used to practice a proposed mission. The data communicated to the remote pilot station can include training and evaluation data for processing and/or display. This training and evaluation data can include any relevant information, such as flight path accuracy, etc.

Simulation Network Interface **609** permits participation in a battlefield simulation system such as SIMNET, mixing aircraft, tanks, and ground troops for training in the coordination of mixed forces. Thus, the system is designed to allow for the communication of this battlefield simulation information between the remote aircraft simulator and the remote pilot station. This allows the remote pilot station to display one or more other simulated entities (e.g., tanks, ground troops, other aircraft, etc.) described by the battlefield simulation information.

The Database

The Digital Database **107** can be comprised of any type of data from which a three dimensional image can be generated. For example, 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.

The other USGS database 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 the remote pilot can select them to be highlighted by category or by specific object.

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

The procedure for generating the synthesized three-dimensional view from the Digital Database may use any number of techniques, including those disclosed in the 1987 patent to Beckwith et al. (U.S. Pat. No. 4,660,157 REAL TIME VIDEO PERSPECTIVE DIGITAL MAP DISPLAY METHOD), and the 1993 patent to Dawson et al. (U.S. Pat. No. 5,179,638 METHOD AND APPARATUS FOR GENERATING A TEXTURE MAPPED PERSPECTIVE VIEW). One disadvantage of generating the synthesized three-dimensional view from these elevation databases in real time is the amount of storage space they require. To avoid this large amount of data storage, one embodiment of Digital Database **107** is composed of terrain data that represents the real terrain using polygons. This database may be generated using any number of techniques. For example, this database may be generated by transforming one or more elevation databases into a polygon database using the technique taught in "Pilot Aid Using a Synthetic Environment", Ser. No. 08/274,394 filed Jul. 11, 1994. Another method for transforming one or more elevation databases into a polygon database is taught in "Digital Map Generator and Display System", Ser. No. 08/543,590, filed Oct. 16, 1995. An example of a three dimensional projected image created from this database is shown in FIG. 7.

While the invention has been described in terms of several embodiments, those skilled in the art will recognize that the invention is not limited to the embodiments described. The method and apparatus of the invention can be practiced with modification and alteration within the spirit and scope of the appended claims. The description is thus to be regarded as illustrative instead of limiting on the invention.

What is claimed is:

1. A system comprising:

a remotely piloted aircraft including,

a position determining system to locate said remotely piloted aircraft's position in three dimensions; and

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

a communications system for communicating flight data between a computer and said remotely piloted aircraft,

said flight data including said remotely piloted aircraft's position and orientation, said flight data also including flight control information for controlling said remotely piloted aircraft;

a digital database comprising terrain data;

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

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

a set of one or more remote flight controls coupled to said computer for inputting said flight control information, wherein said computer is also for determining a delay time for communicating said flight data between said computer and said remotely piloted aircraft, and wherein said computer adjusts the sensitivity of said set of one or more remote flight controls based on said delay time.

2. The system of claim 1, wherein:

said remotely piloted aircraft includes a device for capturing image data; and

said system operates in at least a first mode in which said image data is not transmitted from said remotely piloted aircraft to said computer at a sufficient data rate to allow for real time piloting of the remotely piloted aircraft.

3. The system of claim 1, wherein the flight data communicated between said remotely piloted aircraft and said computer is secured.

4. The system of claim 1, wherein said remotely piloted aircraft further comprises a set of one or more video cameras.

5. The system of claim 4, wherein said communications system is also for communicating video data representing images captured by said set of one or more video cameras, said video data for displaying said images.

6. The system of claim 5, wherein said video data is transmitted on a different communication link than said flight data.

7. The system of claim 4, wherein at least one camera in said set of one or more video cameras is an infrared camera.

8. The system of claim 1, wherein said display is a head mounted display.

9. The system of claim 1, wherein said set of one or more remote flight controls is responsive to manual manipulations.

10. The system of claim 1, wherein said set of one or more remote flight controls allows for inputting absolute pitch and roll angles instead of pitch and roll rates.

11. The system of claim 1, wherein said computer is also used for correcting adverse yaw without requiring input from said set of one or more remote flight controls.

12. The system of claim 1, wherein:

said remotely piloted aircraft includes a device for capturing image data; and said system operates in at least a first mode in which said image data is not transmitted from said remotely piloted craft to said computer but stored in said remotely piloted aircraft.

13. A station for flying a remotely piloted aircraft that is real or simulated comprising:

a database comprising terrain data;

a set of remote flight controls for inputting flight control information;

a computer having a communications unit configured to receive status information identifying said remotely piloted aircraft's position and orientation in three dimensional space, said computer configured to access said terrain data according to said status information and configured to transform said terrain data to provide three dimensional projected image data representing said remotely piloted aircraft's environment, said computer coupled to said set of remote flight controls and said communications unit for transmitting said flight control information to control said remotely piloted aircraft, said computer also to determine a delay time for communicating said flight control information between said computer and said remotely piloted aircraft, and said computer to adjust the sensitivity of said set of remote flight controls based on said delay time; and

a display configured to display said three dimensional projected image data.

14. The station of claim 13, wherein said communications unit is also configured to receive video data representing images captured by a set of video cameras on said remotely piloted aircraft, said video data for displaying said images.

15. The station of claim 14, wherein said video data is transmitted on a different communication link that said flight control information and said status information.

16. The station of claim 13, wherein said display is a head mounted display.

17. The station of claim 13, wherein said set of remote flight controls is responsive to manual manipulations.

18. The station of claim 13, wherein said set of remote flight controls are configured to allow inputting absolute pitch and roll angles instead of pitch and roll rates.

19. The station of claim 13, wherein said computer is also configured to correct adverse yaw without requiring input from said set of remote flight controls.

20. The station of claim 13, wherein said communications unit includes at least one of a communications transceiver and a simulation port.

* * * * *

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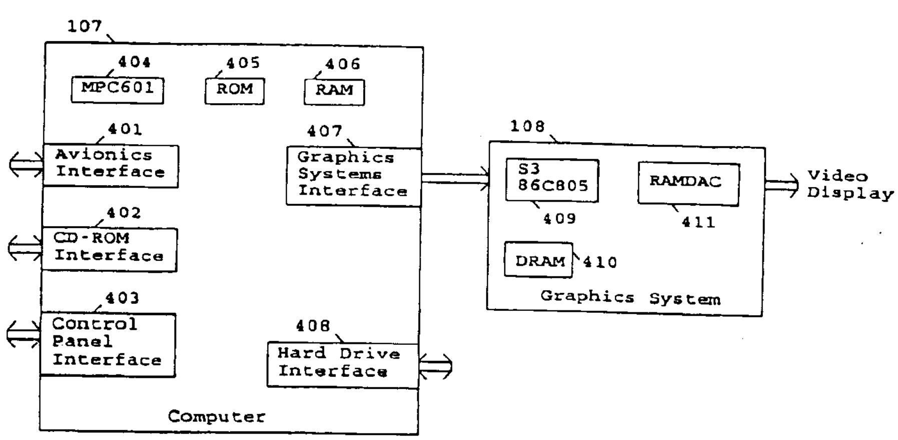
Primary Examiner—Kevin J. Teska
Assistant Examiner—Tan Nguyen
Attorney, Agent, or Firm—Blakely, Sokoloff, Taylor & Zafman

[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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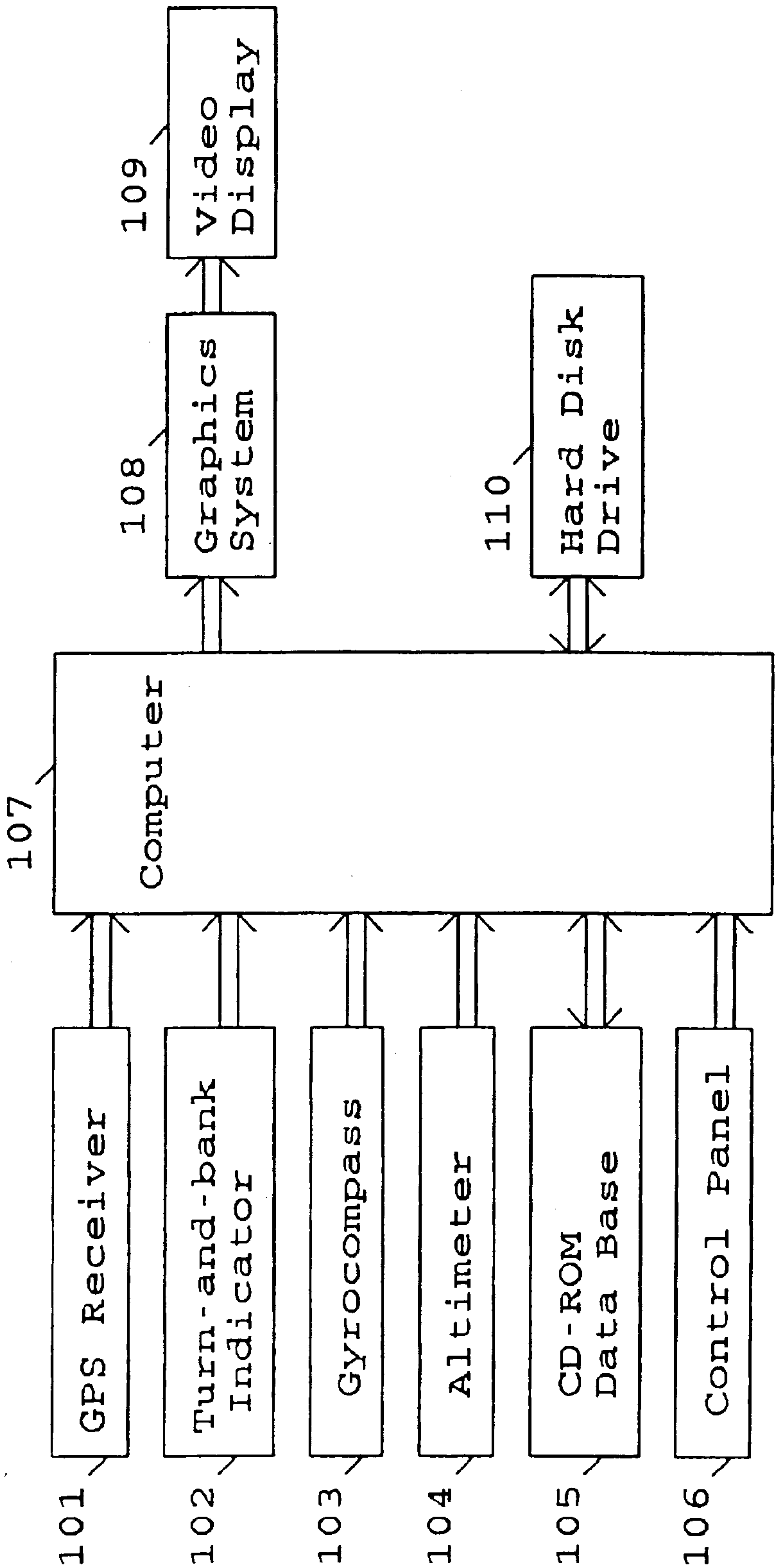
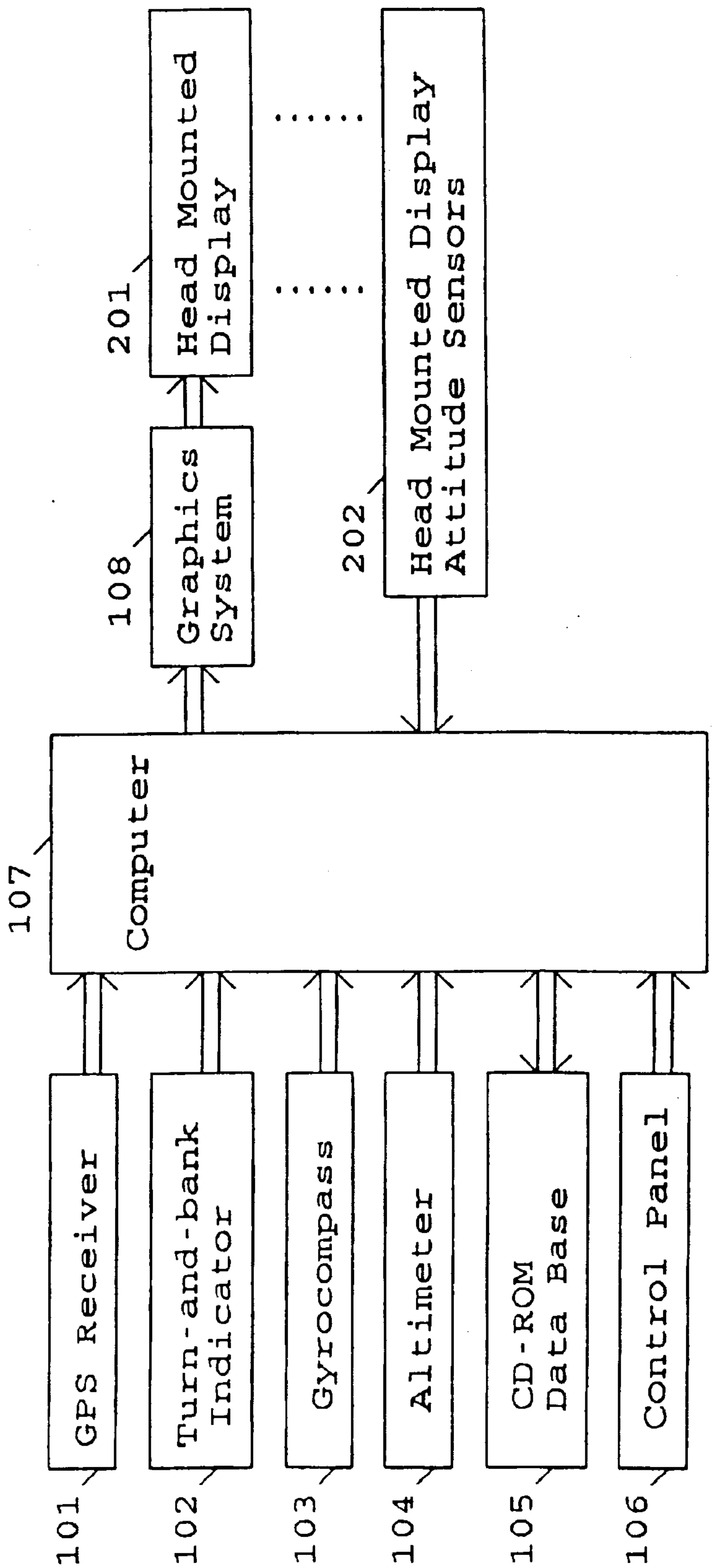

Video Display
109
Graphics System
108
Hard Disk Drive
110
Computer
107
GPS Receiver
Turn-and-bank Indicator
Gyrocompass
Altimeter
CD-ROM Data Base
Control Panel
101
102
103
104
105
106

Fig. 1



201
Head Mounted Display
108
Graphics System
202
Head Mounted Display Attitude Sensors
107
Computer
GPS Receiver
Turn-and-bank Indicator
Gyrocompass
Altimeter
CD-ROM Data Base
Control Panel
101
102
103
104
105
106

Fig. 2

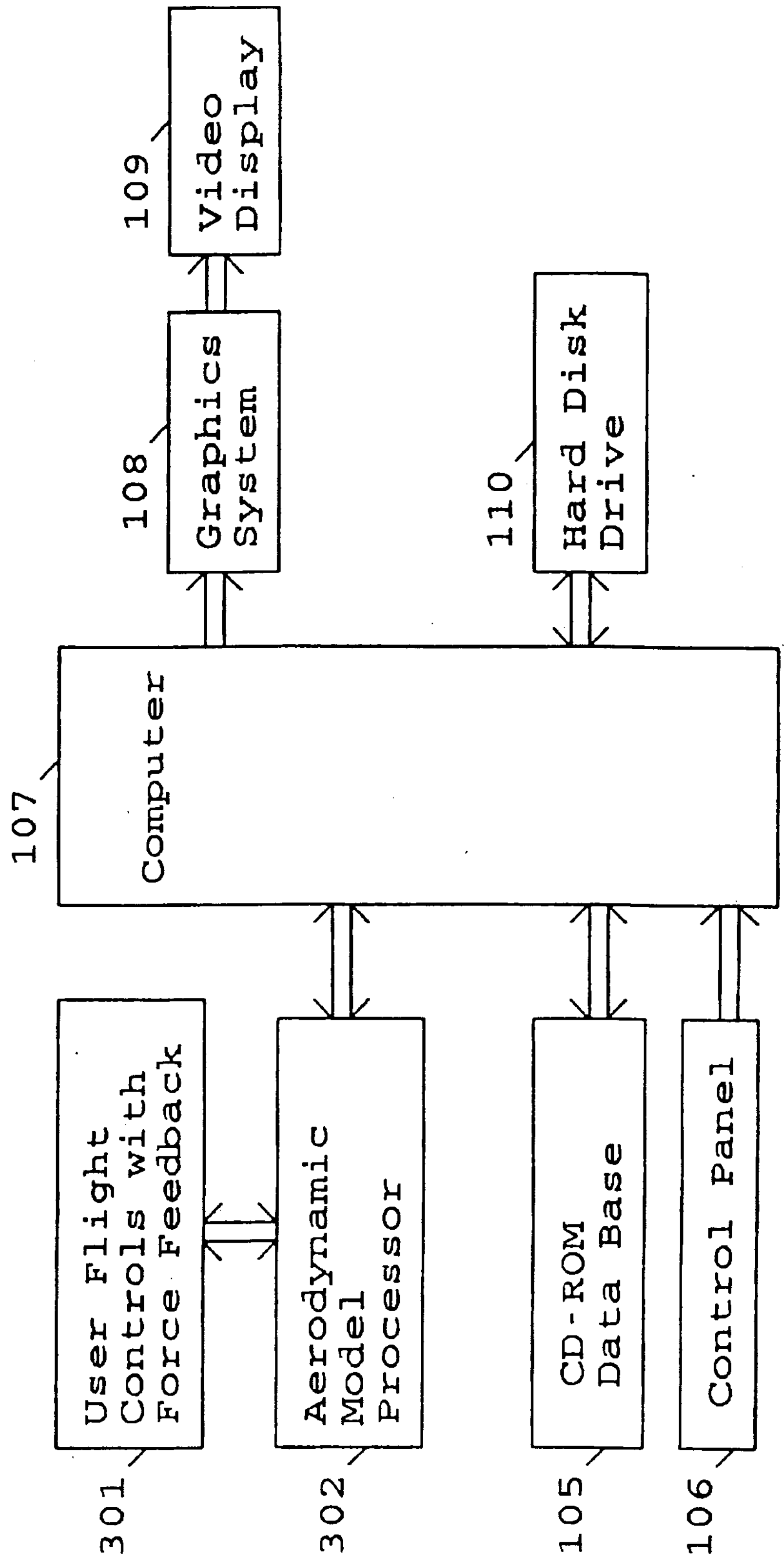

Video Display
109
Graphics System
108
Hard Disk Drive
110
Computer
107
User Flight Controls with Force Feedback
301
Aerodynamic Model Processor
302
CD-ROM Data Base
105
Control Panel
106

Fig. 3

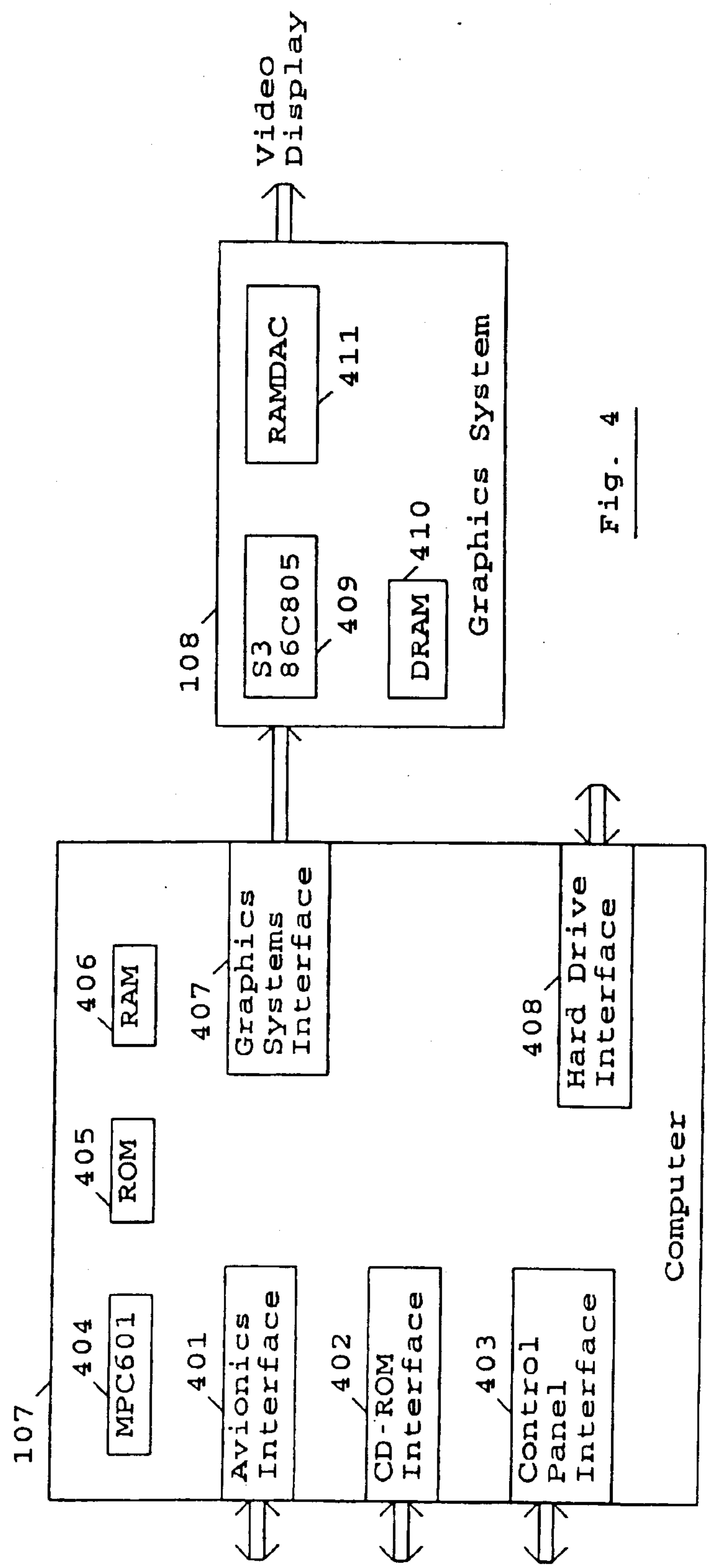

Video Display
108
S3 86C805
409
RAMDAC
411
DRAM
410
Graphics System
107
MPC601
404
ROM
405
RAM
406
Graphics Systems Interface
407
Avionics Interface
401
CD-ROM Interface
402
Control Panel Interface
403
Hard Drive Interface
408
Computer

Fig. 4

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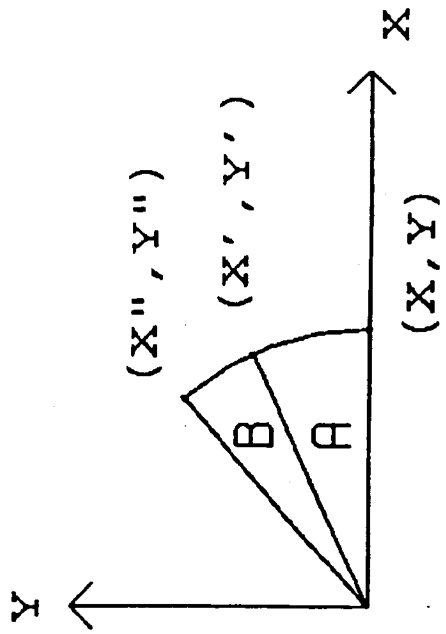

Fig. 5b

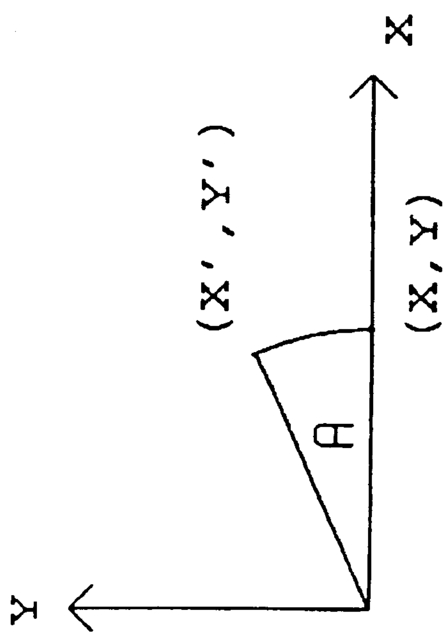

Fig. 5a

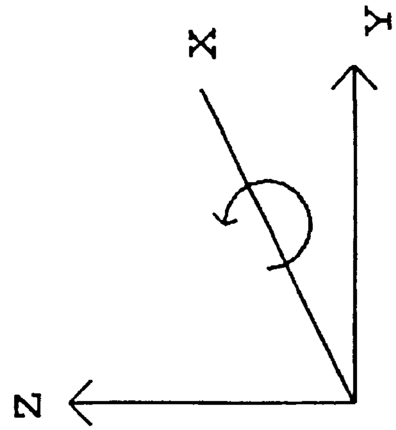

Fig. 6c

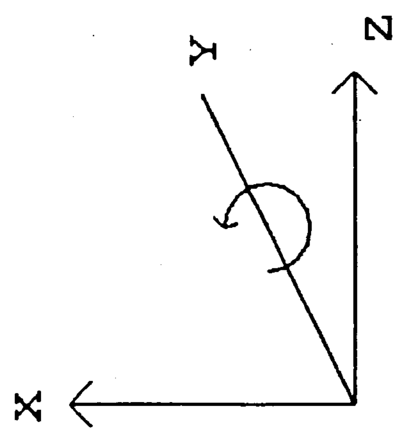

Fig. 6b

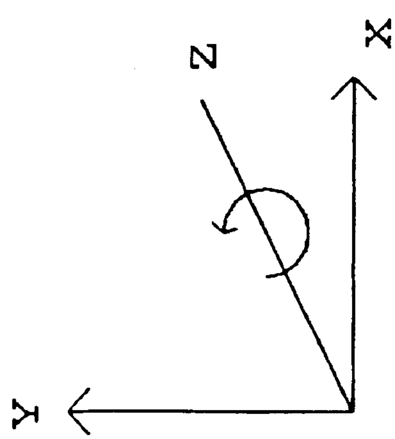

Fig. 6a

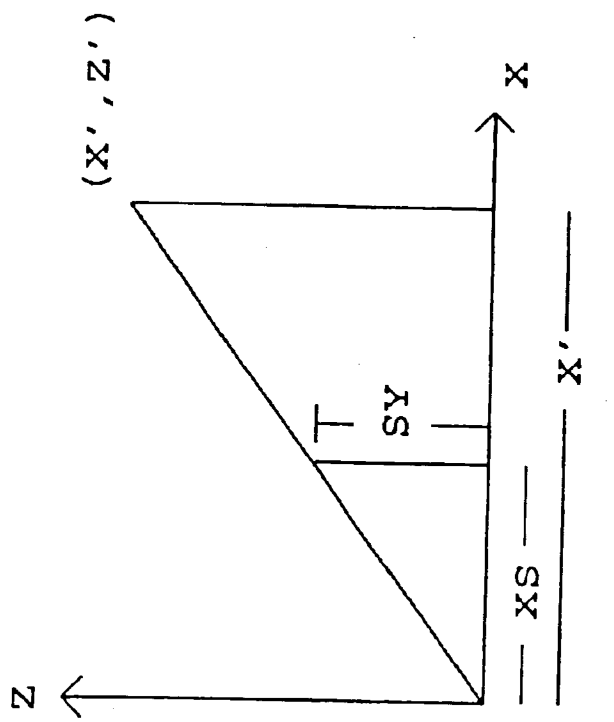

Fig. 7a Side

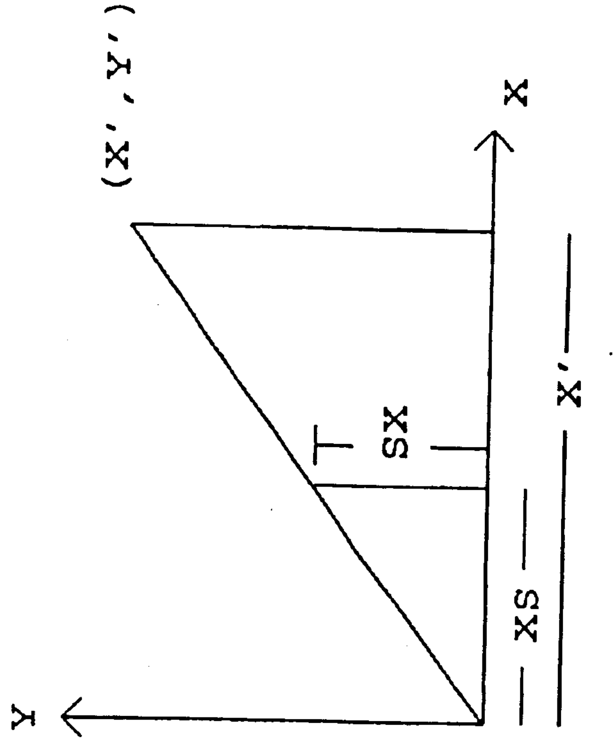

Fig. 7b Top

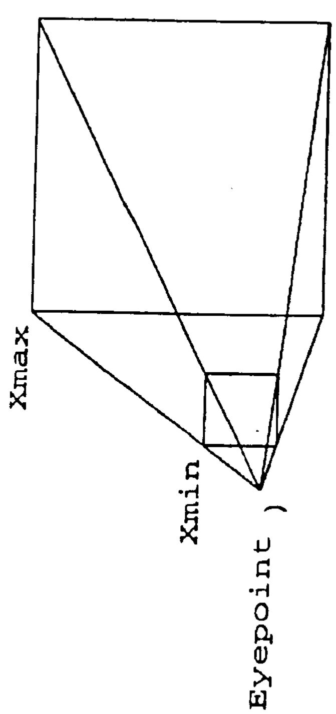

Fig. 8a

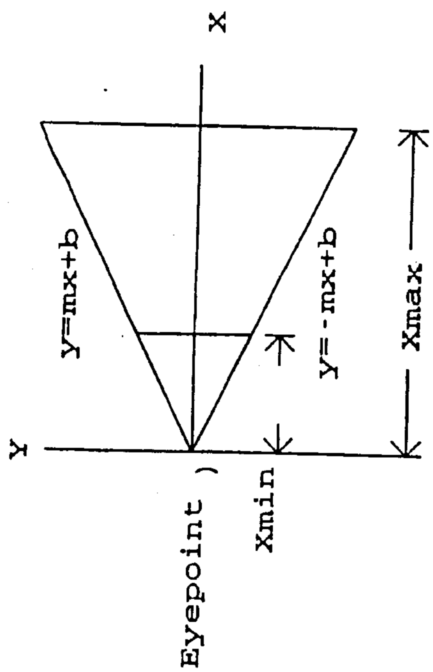

Fig. 8b Top View

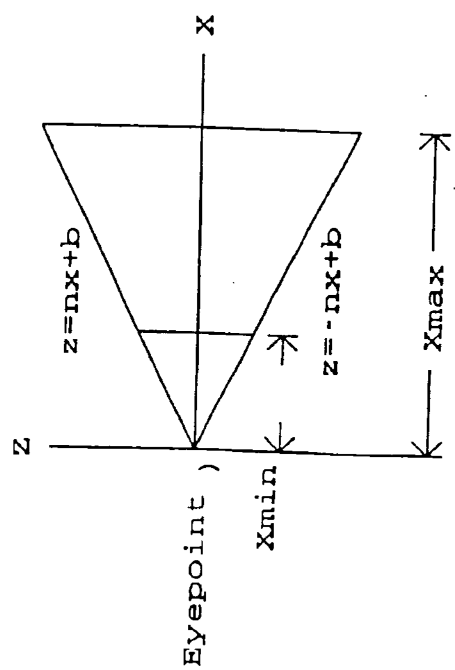

Fig. 8c Side View

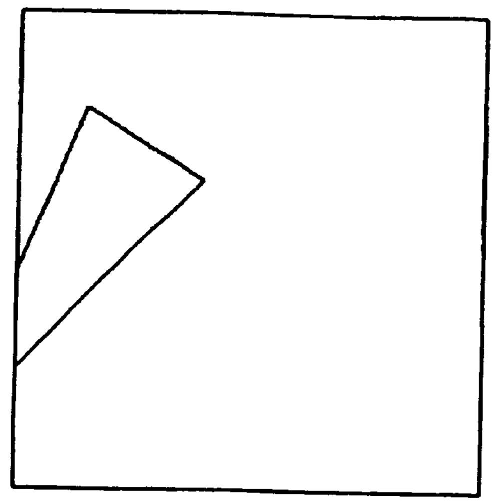

Fig. 9b

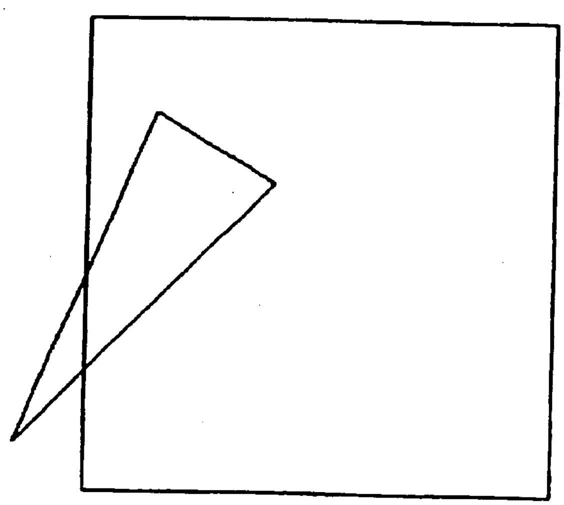

Fig. 9a

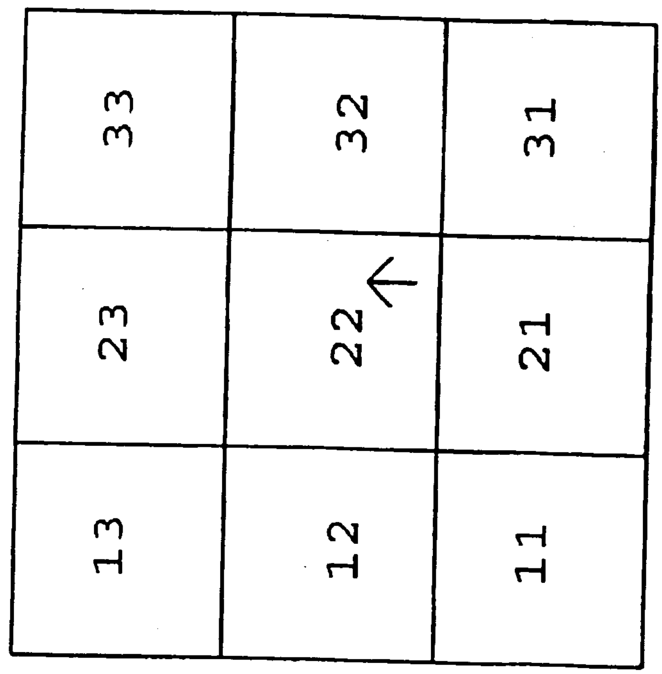

Fig. 10b

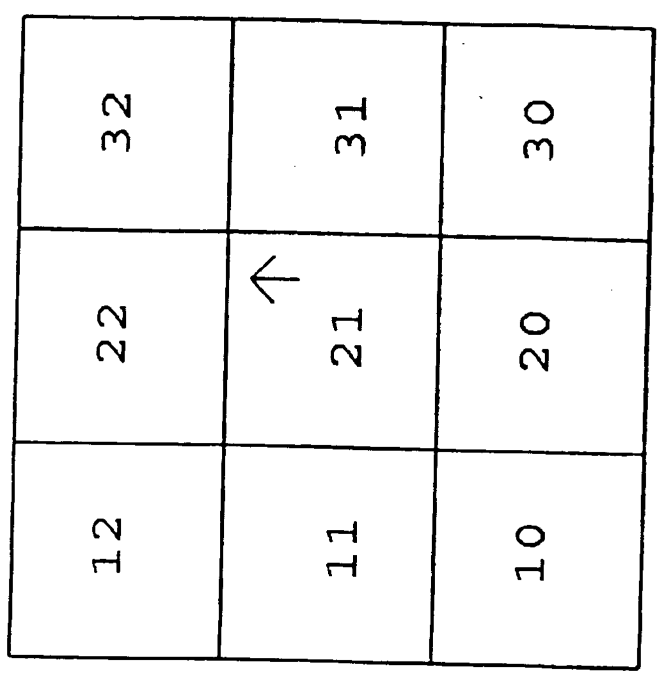

Fig. 10a

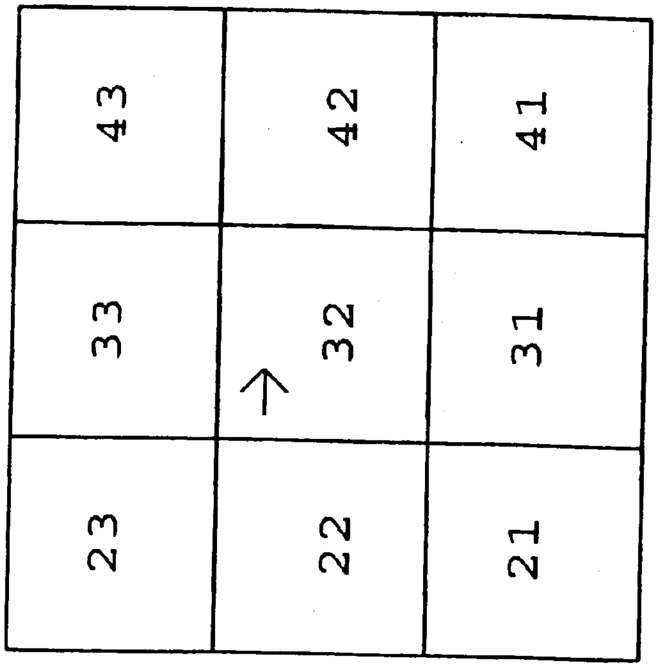

Fig. 11b

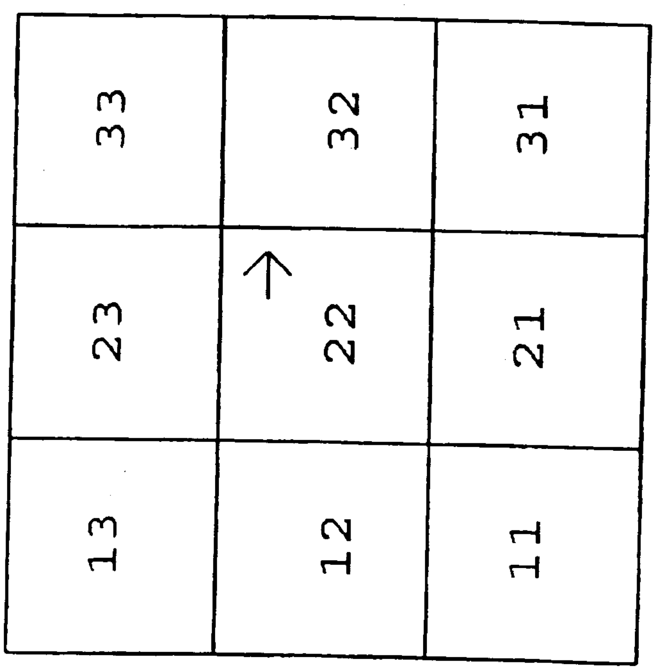

Fig. 11a

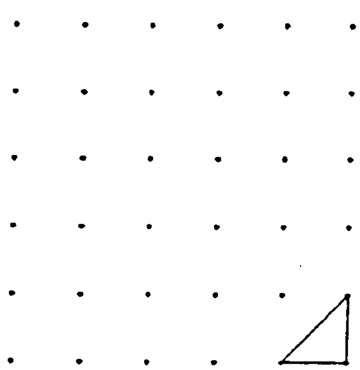

Fig. 12a

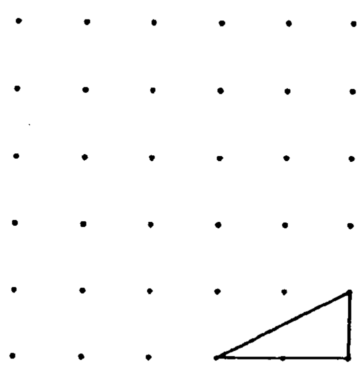

Fig. 12b

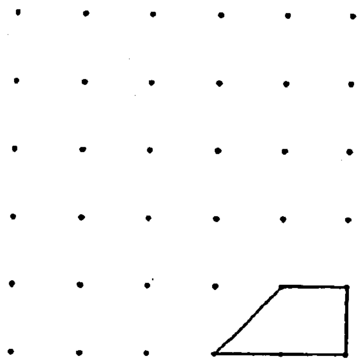

Fig. 12c

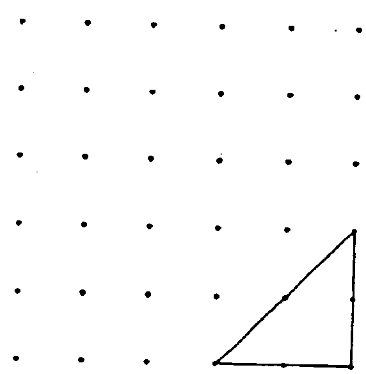

Fig. 12d

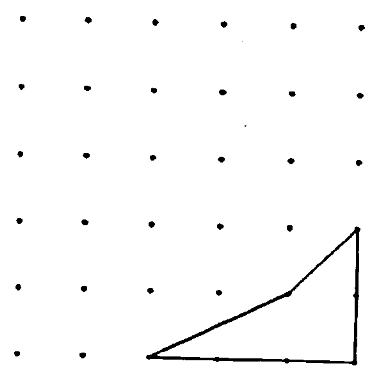

Fig. 12e

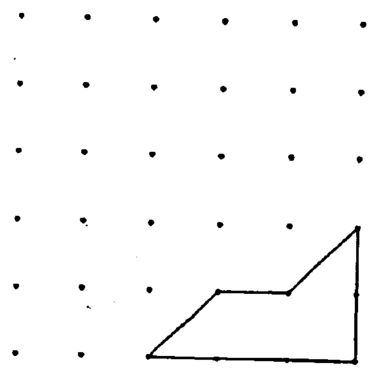

Fig. 12f

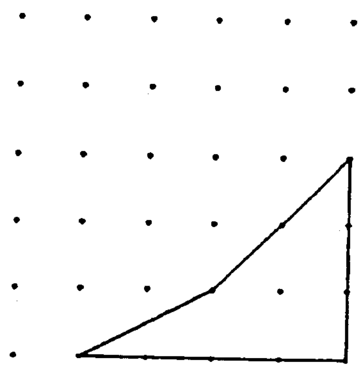
Fig. 13c

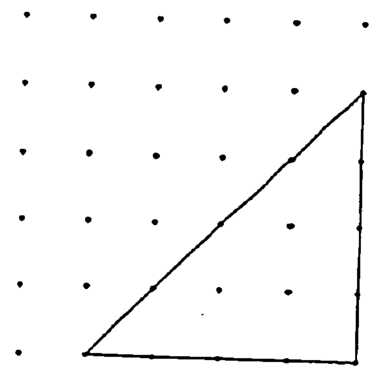
Fig. 13f

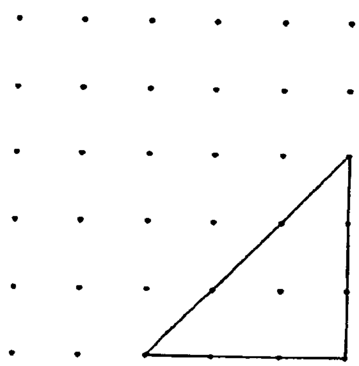
Fig. 13b

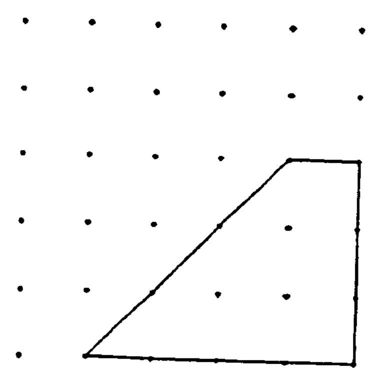
Fig. 13e

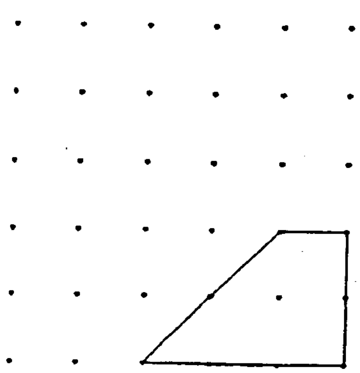
Fig. 13a

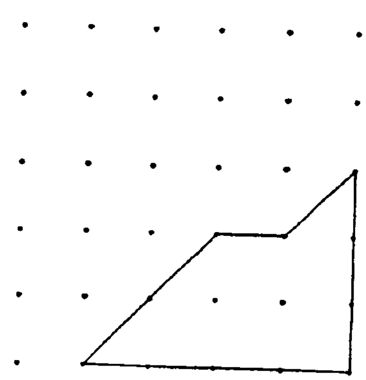
Fig. 13d

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 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.

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. *12f*, and FIG. *13a* through FIG. *13f* 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 1024×768 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 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 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. 5*a* represents a two dimensional space, it is equivalent to a three dimensional space where the rotation is around the Z axis. See FIG. 6*a*. 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:

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

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:

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

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

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

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

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

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

Now let:

EQUATION 12

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

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

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

(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

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

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:

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

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

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

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

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

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

If Pitch:

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

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

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

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

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

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

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

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

and

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

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:

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

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

Ship 1 looks at Ship 2:

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

(Ship 2 orientation relative to Ship 1 orientation)

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

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

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

(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 structure 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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October 13, 2006

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Margolin Patent Nos. 5,566,073 and 5,904,724

Dear Mr. Adams:

We represent Rapid Imaging Software, Inc. (RIS), which has referred to us your letter of September 19, 2006. At the outset, we are unable to discern that Optima has an interest in the patents it attempts to assert. Assuming that it does, however, and has merely neglected to record its interests, RIS does not infringe the Margolin patents.

As you know, RIS creates computer software, and does not use or manufacture UAV systems or ground control stations. RIS software is used in UAVs to provide situation awareness for sensor operators. It is not used for piloting air vehicles. The sensor operator does not pilot the aircraft, and instead sits at a separate workstation operating a payload containing one or more cameras, which may be controlled using a joystick to point the camera package during search or tracking operations.

As you know, RIS refuses to allow its products to be used as a pilot aid, and RIS product licenses specifically prohibit use for piloting. None of RIS's customers use its software for piloting, for very good reason. Serious military regulations control placement of anything—synthetic vision included—on a pilot workstation. Before anything can be placed on the display in front of a pilot, it has to have met stringent criteria (MIL-STD 1787C, DO-178B, etc.), it must have been thoroughly ground tested, and it must have been fully flight tested. RIS software has never been through this process, and thus is prohibited from use for piloting. Accordingly, UAV manufacturers have purchased RIS products for use on the sensor operator console, but none for the pilot console. This is a matter of Army doctrine and applies to Shadow, Warrior and Hunter.

Nor does RIS have its software in a form that would make it marketable for piloting. RIS software products are all based on the Microsoft Windows operating system. This offers many advantages, but is inappropriate to piloting aircraft because it is a not a POSIX compliant real-time operating system. POSIX compliance is required by flight safety regulations. To create such a version would entail a one- to two-year conversion program in which RIS has not invested.

It is important to realize that the market for RIS products is quite different from the relaxed civilian world. If a military pilot chose to use synthetic vision in spite of military regulations or in defiance of a software license agreement, his career would be damaged or destroyed. Military pilots cherish their wings and would not consider risking them on something like synthetic version.

Finally, it appears from your correspondence that you regard research activities like NASA's X-38 prototypes (before the program was cancelled in 2002) as infringing the Margolin patents. This was not the case because of the claim limitations of the Margolin patents. However all RIS work for government agencies, including NASA, was authorized and consented to by the U.S. Government, and is protected under 28 U.S.C. § 1498(a). As you are aware, any remedies you may have are against the government and are circumscribed by that statute and related law.

Although we need not discuss the invalidity of the Margolin patents given the above circumstances, you should be aware that both patents were anticipated by profound prior art dating back to 1977. If it should ever become necessary, we are confident that both would be held invalid.

Very truly yours,

Benjamin Allison
Santa Fe Office

BA:gmr
Enclosures
841473

cc: Mike Abernathy

Synthetic Vision Technology for Unmanned Aerial Vehicles: Historical Examples and Current Emphasis

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Background – Flight Simulation Real-Time 3D Computer Graphics

In the aviation context, synthetic vision can be described, in simplest terms, as the use of a computer and a terrain database to generate a simulated 3D view of an environment in real time. The application of synthetic vision to remotely piloted vehicles (RPVs) and unmanned aerial vehicles (UAVs) goes back three decades and has recently evolved from a piloting aid for UAV pilots to a potentially powerful tool for sensor operators [1]. It is anticipated that integration of this technology can ameliorate many factors that currently compromise the utility of UAV video imagery: narrow camera field-of-view, degraded datalinks, poor environmental conditions, limited bandwidth, and highly cluttered visual scenes such as in urban areas. With this technology, spatially-relevant information, constructed from databases (e.g., terrain elevation, cultural features, maps, photo imagery) as well as networked information sources, can be represented as computer-generated imagery and symbology overlaid conformal, in real time, onto a dynamic video image display. This computer-generated imagery and symbology appears to co-exist with real objects in the visual scene, highlighting points of interest and helping the operator maintain situation awareness of the environment. The purpose of this paper is to briefly summarize the evolution of this technology towards RPV/UAV applications.

The story begins in the 1970's when the use of computers to create 3D real-time out-the-window synthetic environments was beginning to see wide acceptance for training pilots of manned aircraft. Evans and Sutherland (E & S) had seen the commercial potential for flight simulation and had introduced special purpose graphics computers, like their Picture System, which transformed and projected 3D terrain data as simple 3D polygons to a pilot's perspective view in real-time (30 Hz) [2]. In 1975 an engineering student named Bruce Artwick wrote "Flight Simulator" for the Apple II computer [3]. He formed a company and in 1980 marketed the product that ultimately became Microsoft Flight Simulator®.

In fact it was this phenomenon – the emergence of computer flight simulation in the 1970s – that appears to have sparked a monumental amount of research. The Air Force began its Visually Coupled Airborne Systems Simulator (VCASS) program, with a particular eye toward future generation fighters [4]. NASA was developing synthetic vision for the Super Sonic Transport and for its High Maneuverability Aircraft Testbed (HiMAT) RPV program. Educational institutions studied the limitless new possibilities for virtual reality human-machine interfaces. By the mid-1980s, synthetic vision for RPV simulation was even commercially available for radio control aircraft hobbyists.

Actually, there is a large body of research from the 1970s to the present that addresses the application of synthetic vision to manned and unmanned aircraft. In the interest of brevity, we will focus on select systems that were important enablers towards UAV synthetic vision systems.

Pictorial Format Avionics Displays

In 1977, NASA researchers published "Pathway-in-the-Sky Contact Analog Piloting Display" [5], which included a complete design for a synthetic vision system. It featured a computer that projected a 3D view of the terrain, given the aircraft's position and orientation. This out-the-window perspective view was displayed on a CRT type display. Such displays were called "Pictorial Format" avionics systems, but we recognize them as containing all of the essential elements of a modern synthetic vision display.

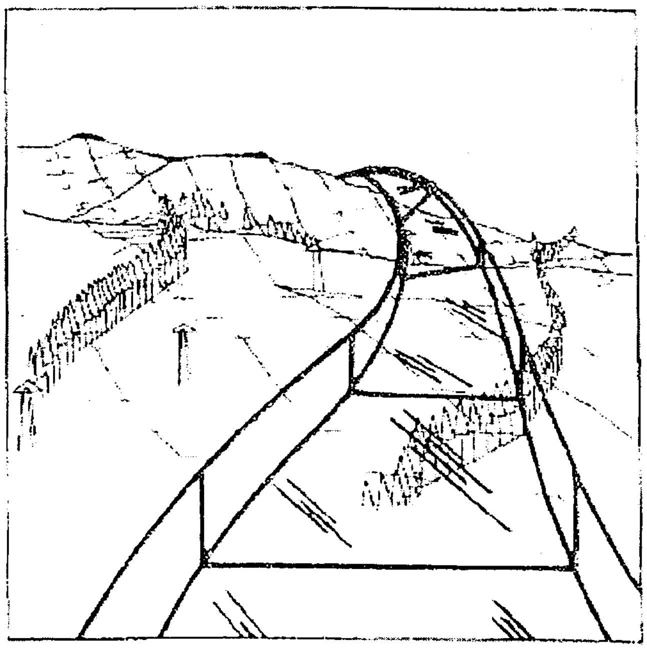

Figure 1 1984 USAF pictorial format avionics synthetic vision display.

In 1979 the Air Force completed its "Airborne Electronic Terrain Map Applications Study (AETMS)", and in 1981 published "The Electronic Terrain Map: A New Avionics Integrator" describing how a computerized terrain database could be displayed as an out-the-window 3D view allowing the pilot to "see" even at night and in other limited visibility situations [6].

Also in 1979, the Air Force published research [7] identifying human factors problems that would have to be overcome in RPV cockpit design. NASA would use this in the design of the HiMAT RPV 3D visual system in 1984.

Pictorial format avionics (i.e., synthetic vision) formed a key ingredient of the Air Force Super Cockpit concept. This program included a bold future vision in which "*the pilot need not be present in the actual vehicle which he is piloting since with the appropriate data links a "remote" super cockpit would provide the visual and aural "telepresence" cues as if he were located in the vehicle*" according to Air Force researcher Tom Furness [8].

Figure 2. USAF Super cockpit helmet, simulator, and sample visual format (photo courtesy http://www.hitl.washington.edu)

HiMAT: Remotely Piloted Aircraft with Synthetic Vision

In 1984, NASA published research that investigated synthetic vision for lateral control during RPV landings [9]. These tests featured the USAF/NASA HIMAT (High Maneuverability Aircraft Testbed), a remotely piloted research vehicle flown at Dryden Flight Research Center. These aircraft (Figure 3) were dropped from a B-52 and remotely piloted from a ground station to a landing on the lakebed. The vehicle had a nose camera which produced video that could be shown in the remote cockpit, allowing the comparison of nose camera imagery versus synthetic vision during pilot testing.

Vehicle position was computed using RADAR computations, along with a radio altimeter. Electro-mechanical gyroscope systems were installed onboard the RPV aircraft and measured the 3D attitude of the vehicle. The position and attitude were down-linked from the RPV to a remote cockpit, and pilot control inputs were up-linked from the remote cockpit via the radio communication system [10].

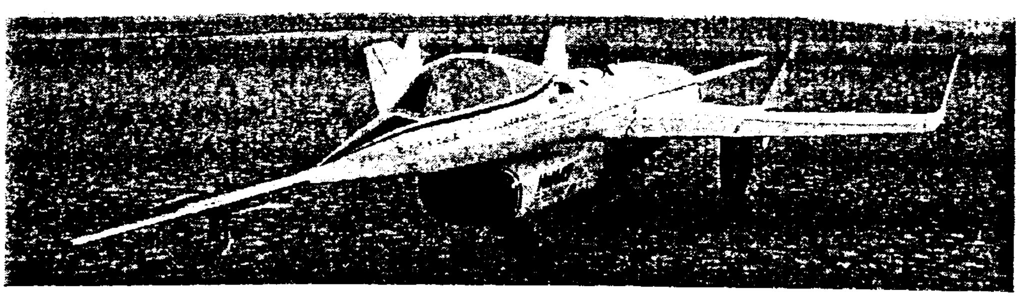

Figure 3. HiMAT Remotely Piloted Vehicle after flight at Dryden Flight Research Center. (Photo courtesy NASA)

The remote cockpit (Figure 4) included a joystick and rudder controls connected to the computer and control signals were up-linked to the RPV. The computer compensated for delays in the control/communications loop [10].

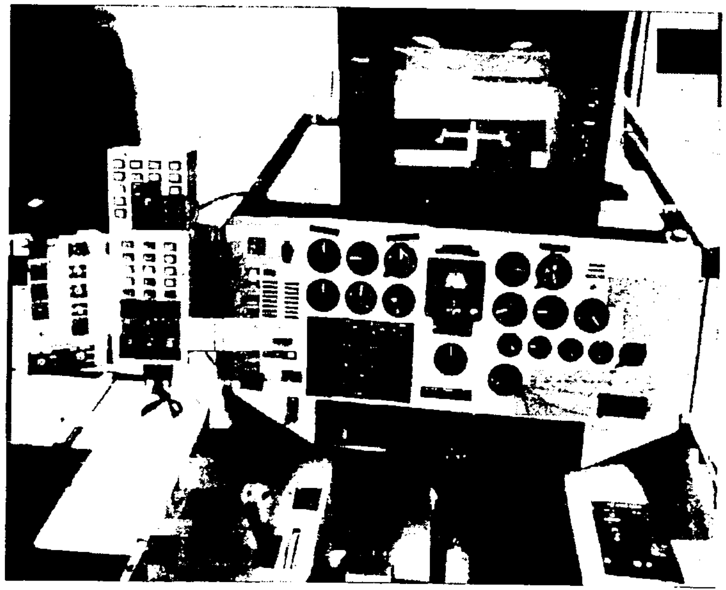

Figure 4. HiMAT RPV remote cockpit showing synthetic vision display (photo courtesy of NASA)

The Edwards Air Force Base dry lake bed and runway were represented in three dimensions in the terrain database as polygons (triangles and rectangles). An Evans and Sutherland (E&S) Picture System computer transformed the terrain in the database into a projected 3D out-the-window view at the pilot cockpit. Finally, the projected 3D out-the-window view was displayed on an E&S Calligraphic video display system capable of 4000 lines of resolution (Figure 5). According to the pilots participating in the study, the synthetic vision compared well to the nose camera view. By the mid 1990s, NASA had migrated the RPV synthetic vision concept used on HiMAT to PC computers for X-36 and on X-38 [11].

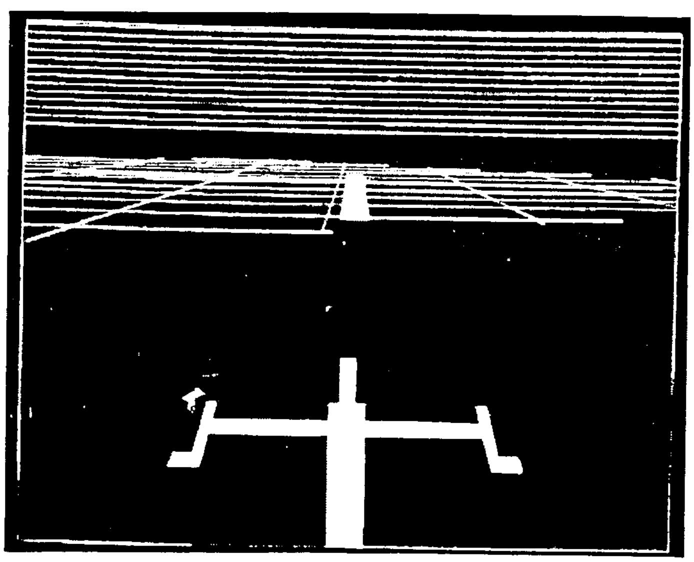

Figure 5. HIMAT synthetic vision display showing terrain and runway. Note the synthetic vision representation of the HiMAT nose probe at center bottom.

Synthetic Vision for Recreational Remotely Piloting Vehicles

One of the early uses of synthetic vision for RPVs was recreational simulation. In 1986 Ambrosia Microcomputer Products introduced RC AeroChopper, a radio controlled aircraft simulator which enabled pilots to learn to fly a remotely controlled aircraft, without risk to their aircraft.,. According to the AeroChopper Owner's Manual [12], the product accepted aileron, elevator, rudder, and throttle pilot inputs via joysticks to control the simulated aircraft. The product also contained data files containing a 3D terrain database provided with AeroChopper representing the earth's surface as well as buildings and obstructions.

The software was run on a computer (an Amiga for example) and was connected to the flight controls and communicated the aircraft position and attitude in three-space to the user. The computer used the terrain data to create a projected view of the aircraft and its environment in three dimensions (Figure 6). Like most visual simulations of its time, the program used relatively few polygons to represent the terrain and man-made objects, and so looks relatively crude by today's standards.

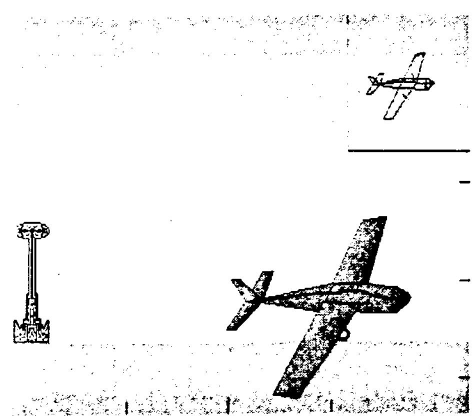

Figure 6. This 3D synthetic vision simulation display for radio controlled aircraft is from RC AeroChopper.

Synthetic Vision for Sensor Operations

Although most of the historical focus with synthetic vision has been on aiding flight management, recent efforts have focused on how synthetic vision can aid UAV sensor operator functions. Ongoing research at the US Air Force Research Laboratory's Human Effectiveness Directorate is exploring how to improve UAV sensor operator utility of video imagery. The overall objective is to determine the value of combining synthetic vision imagery/symbology with live camera video presented on a UAV control station camera display. One research study [13] evaluated the utility of computer-generated video overlays for four different task types: controlling the camera to locate specific ground landmarks in the 360 degree area surrounding the loitering UAV, designating multiple ground targets marked with synthetic symbology, tracing a synthetically highlighted ground convoy route with the UAV camera boresight, and reading text from synthetic overlaid symbology. UAV telemetry update rate was manipulated from 0.5 Hz to 24 Hz. The results indicated the potential of synthetic symbology overlay for enhancing situation awareness, reducing workload, and improving the designation of points of interest, at nearly all the update rates evaluated and for all four task types. However, data across the task types indicated that update rates larger than 2-4 Hz generally resulted in improved objective performance and subjective impressions of utility.

A second research area focused on a picture-in-picture (PIP) concept where video imagery is surrounded by a synthetic-generated terrain imagery border on the physical camera display, increasing the operator's instantaneous field-of-view (Figure 7). Experimental data showed that the PIP helps mitigate the "soda-straw effect", reducing landmark search time and enhancing operator situation awareness. In an evaluation [14] examining the impact of PIP display size and symbology overlay registration error, results indicated that performance on a landmark search task was particularly better with the more compressed video imagery (Figure 7c), reducing average designation time by 60%. Also, the registration error between the virtual flags and their respective physical correlates was less critical with the PIP capability enabled.

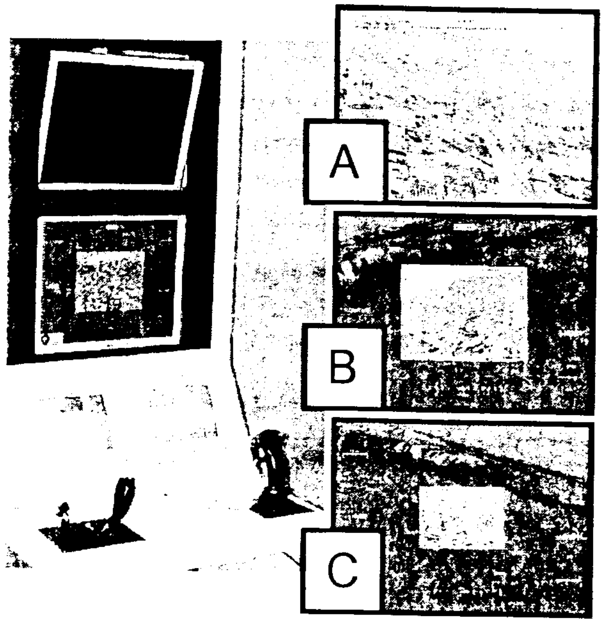

Figure 7 UAV Control Station Simulator. (A: no picture-in-picture (PIP), B: video imagery compressed to 50% original size, C video imagery compressed to 33% original size.)

Summary

More than three decades of research regarding synthetic vision for RPVs and UAVs began with the emergence of computers and display systems capable of creating real-time 3D projected moving displays. This research was conducted by the US Air Force, NASA, US Army, and numerous commercial and educational entities. Several systems, including the NASA HiMAT in 1984, demonstrated the utility for synthetic vision in remotely piloting aircraft and simulated aircraft. The recent availability of sophisticated UAV autopilots capable of autonomous flight control has fundamentally changed the paradigm of UAV operation, potentially reducing the utility of synthetic vision for supporting UAV piloting tasks. At the same time, research has demonstrated and quantified a substantial improvement in the efficiency of sensor operations through the use of synthetic vision sensor fusion technology. We expect this to continue to be an important technology for UAV operation.

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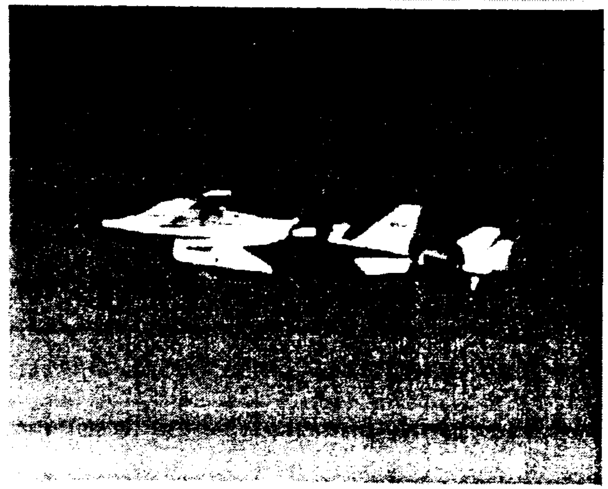
Highly Maneuverable Aircraft Technology

From Wikipedia, the free encyclopedia

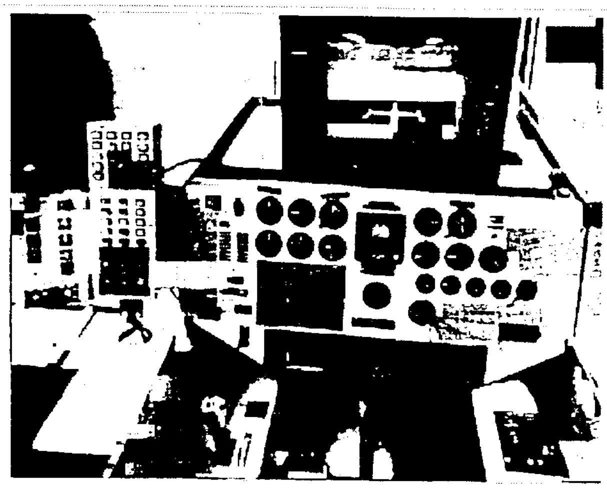
Highly Maneuverable Aircraft Technology (HiMAT) was a NASA-program to develop technologies for future fighter aircraft. Among the technologies explored were close-coupled canards, fully digital flight control (including propulsion), composite materials (graphite and fiberglass), Remotely Piloted Aircraft, Synthetic vision, winglet etc. The winning design was produced by Rockwell International.



HiMAT in flight.

The HiMat were actually remotely piloted aircraft, as the design team decided that it would be cheaper and safer to not have a pilot on board who could be killed in the event of a crash. This also meant that no ejection seat would have to be fitted. According to a report by Sarrafian in 1984, the aircraft was flown by a pilot in a remote cockpit, and control signals up-linked from the flight controls in the remote cockpit on the ground to the aircraft, and aircraft telemetry downlinked to the remote cockpit displays. The remote cockpit could be configured with either nose camera video or with a 3D synthetic vision display called a "visual display" (Sarrafian 1984).

First flight was in 1979 and testing was completed in 1983 and the two HiMat aircraft are now on display, one at the National Air and Space Museum and the other at the NASA Ames Research Center.



HiMAT Remote Cockpit with Synthetic Vision Display (Photo: NASA 1984)

See also

- List of experimental aircraft
- X-29
- X-31
- X-36
- X-38

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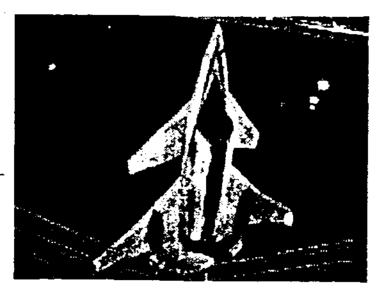

A HiMat at the National Air and Space Museum

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US005904724A

United States Patent [19]

Margolin

[11] **Patent Number:** **5,904,724**

[45] **Date of Patent:** **May 18, 1999**

[54] **METHOD AND APPARATUS FOR REMOTELY PILOTING AN AIRCRAFT**

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

[21] Appl. No.: **08/587,731**

[22] Filed: **Jan. 19, 1996**

[51] **Int. Cl.^{6}** **G06F 165/00**; H04N 7/18

[52] **U.S. Cl.** **701/120**; 701/2; 701/24; 244/189; 244/190; 348/114

[58] **Field of Search** 364/423.099, 424.012, 364/424.013, 424.021, 424.022, 449.2, 449.7, 460, 439, 424.028; 340/825.69, 825.72, 967, 989, 991, 992, 993; 244/189, 190, 181, 17.13, 3.11, 3.15; 348/42, 51, 113, 114, 117, 123, 143; 382/154; 395/118, 119, 125

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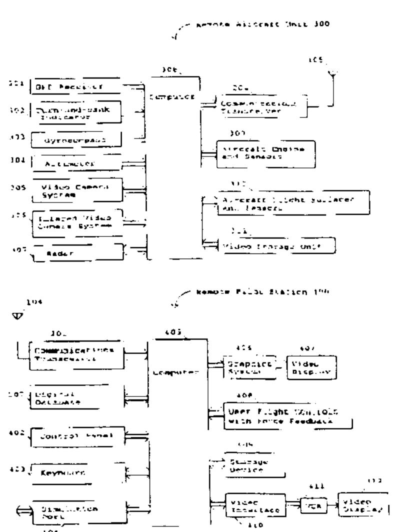
Primary Examiner—Tan Q. Nguyen

Attorney, Agent, or Firm—Blakely, Sokoloff, Taylor and Zafman LLP

[57] **ABSTRACT**

A method and apparatus that allows a remote aircraft to be controlled by a remotely located pilot who is presented with a synthesized three-dimensional projected view representing the environment around the remote aircraft. According to one aspect of the invention, a remote aircraft transmits its three-dimensional position and orientation to a remote pilot station. The remote pilot station applies this information to a digital database containing a three dimensional description of the environment around the remote aircraft to present the remote pilot with a three dimensional projected view of this environment. The remote pilot reacts to this view and interacts with the pilot controls, whose signals are transmitted back to the remote aircraft. In addition, the system compensates for the communications delay between the remote aircraft and the remote pilot station by controlling the sensitivity of the pilot controls.

20 Claims, 7 Drawing Sheets



Helen — Rest of patent not faxed to you.

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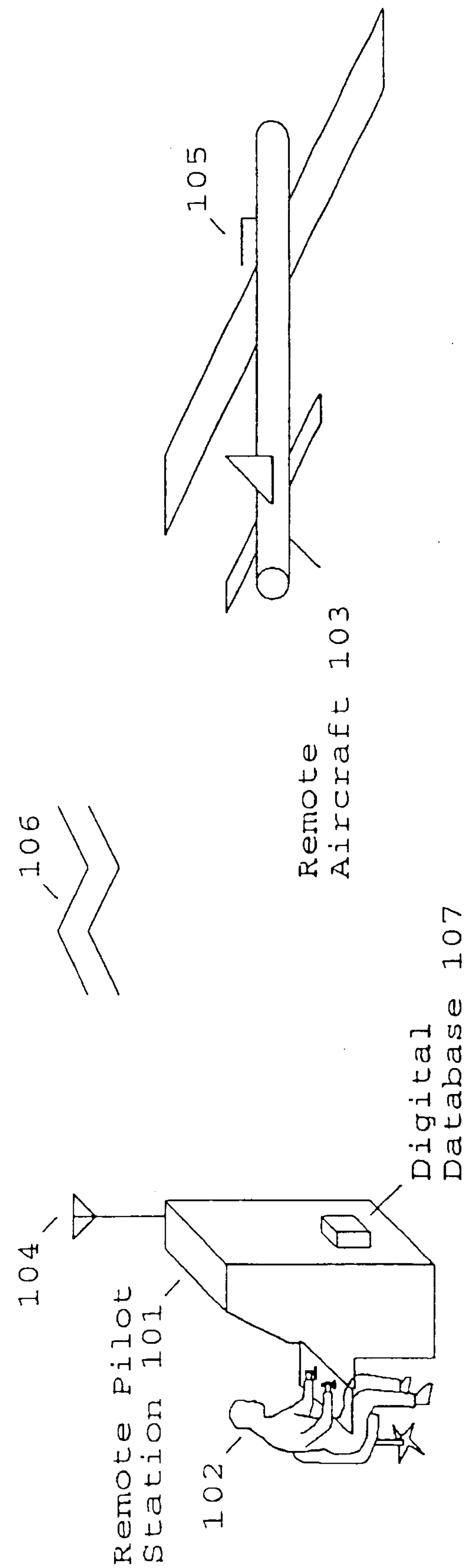

105
Remote Aircraft 103
106
Digital Database 107
104
Remote Pilot Station 101
102

Fig. 1

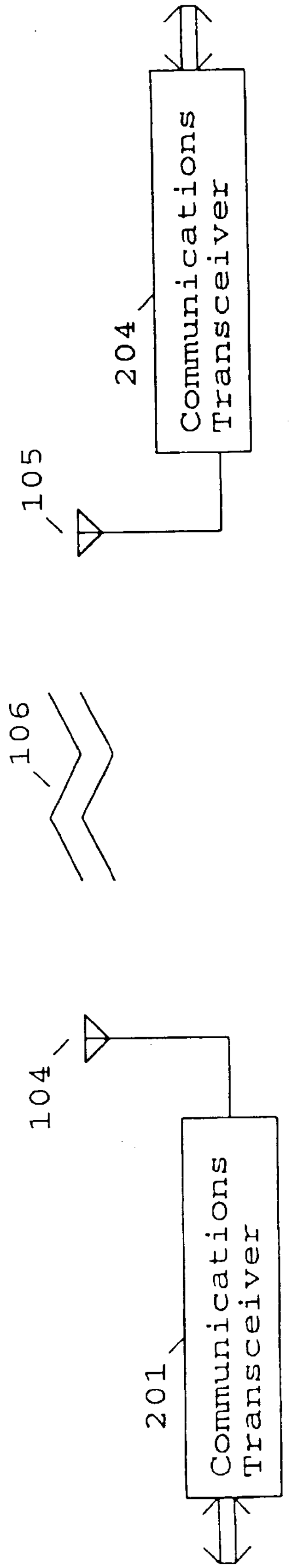

Communications Transceiver
204
105
106
104
Communications Transceiver
201

Fig. 2

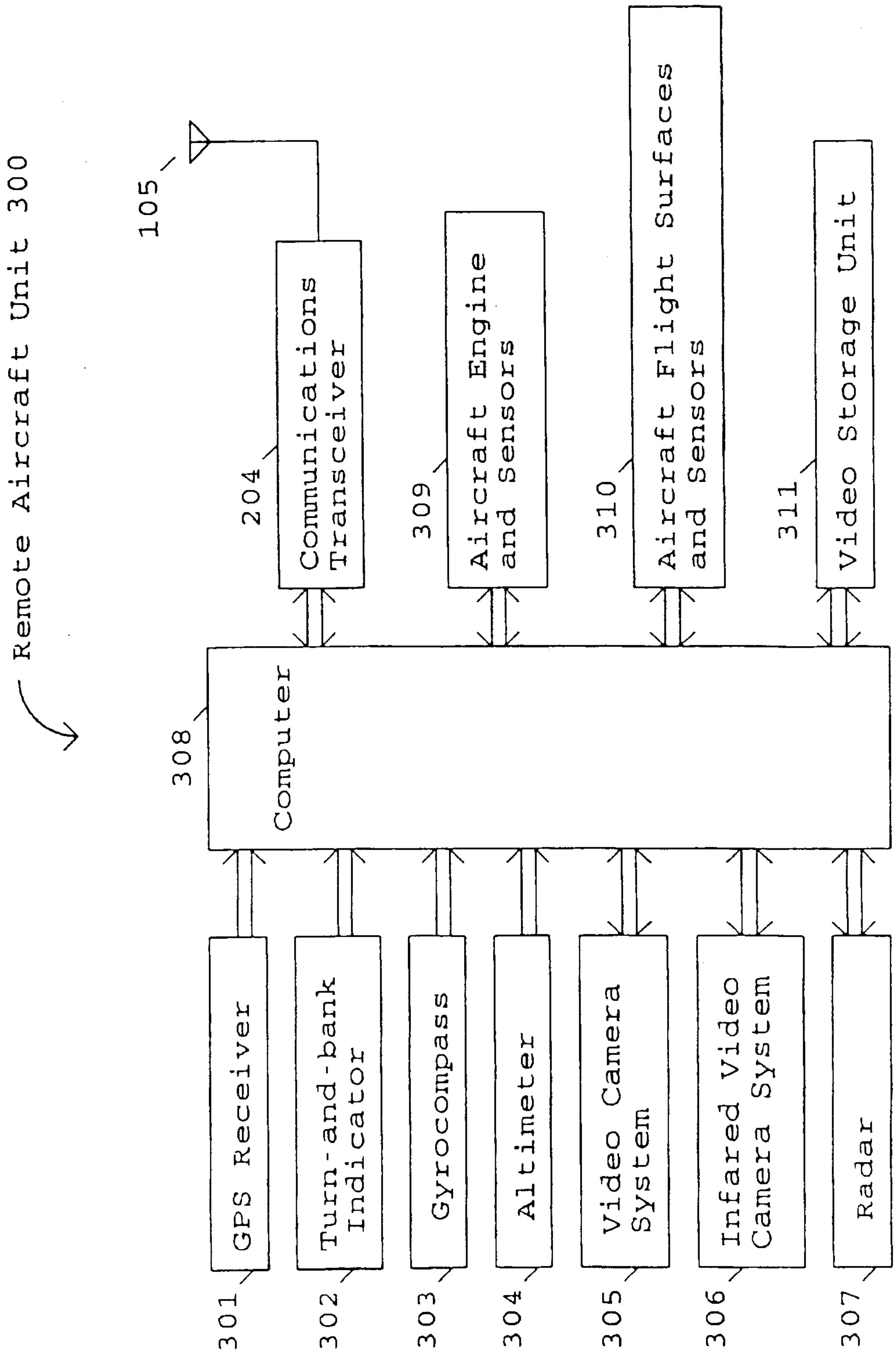

Remote Aircraft Unit 300
105
204
Communications Transceiver
309
Aircraft Engine and Sensors
310
Aircraft Flight Surfaces and Sensors
311
Video Storage Unit
308
Computer
GPS Receiver
Turn-and-bank Indicator
Gyrocompass
Altimeter
Video Camera System
Infared Video Camera System
Radar
301
302
303
304
305
306
307

Fig. 3

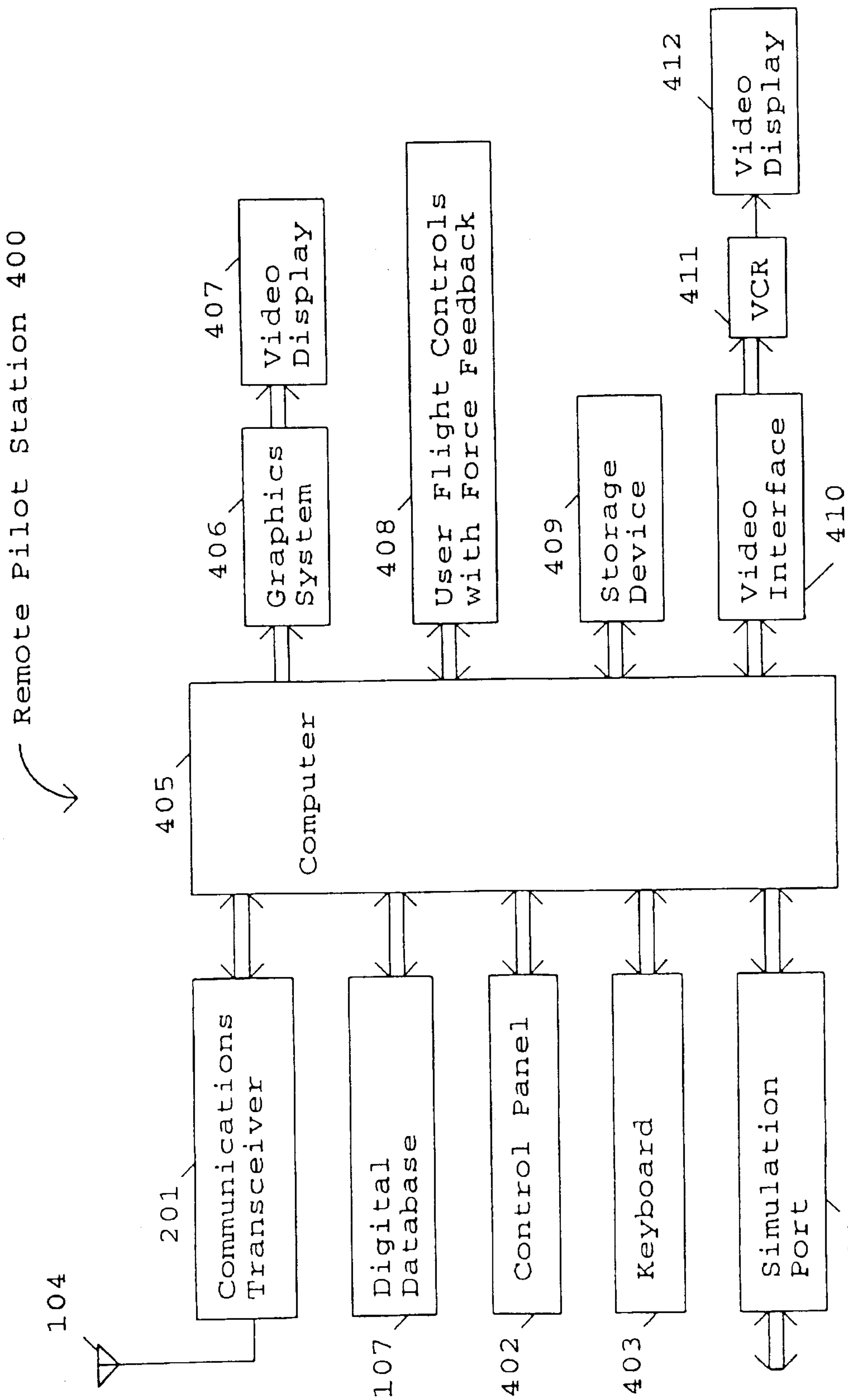
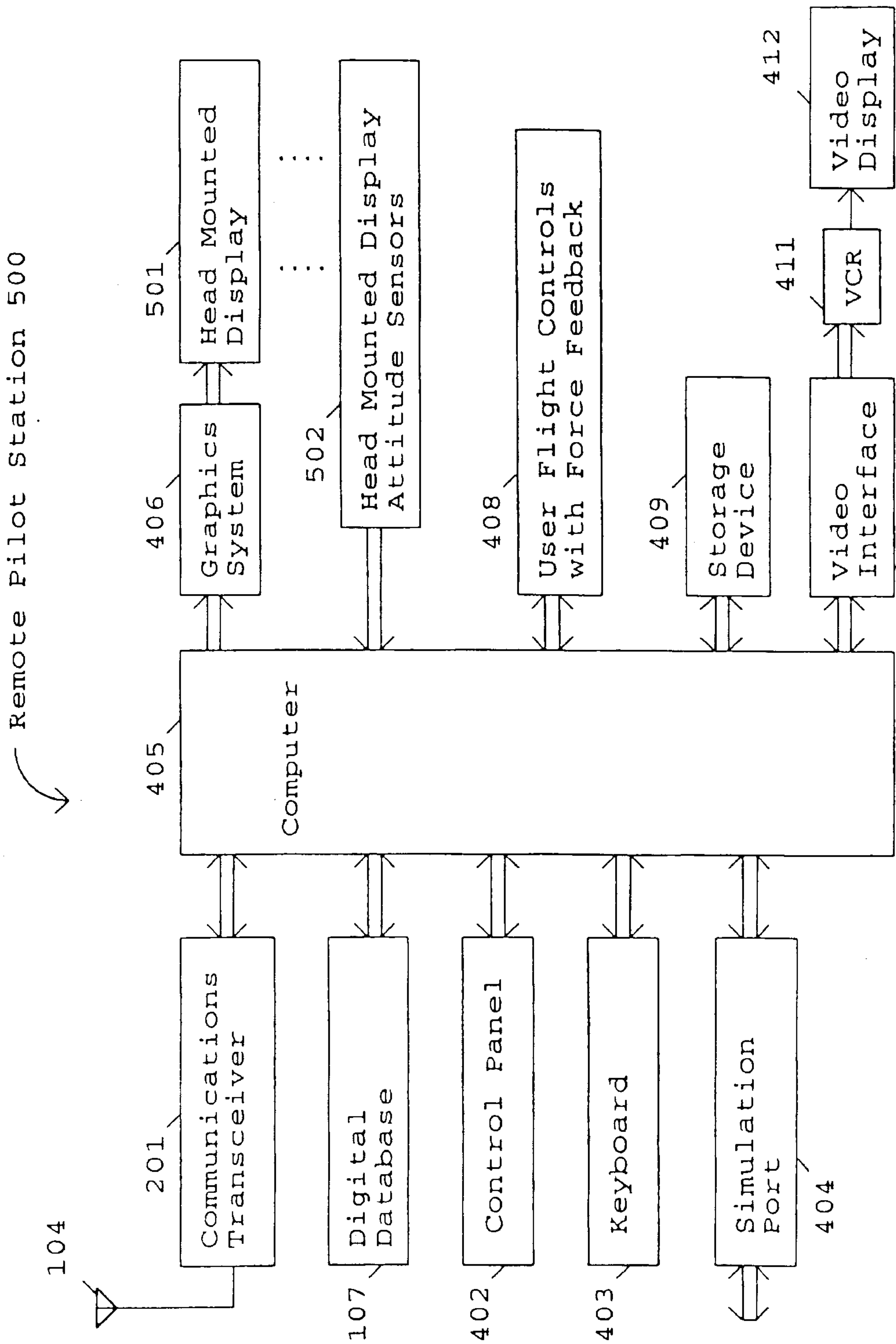

Remote Pilot Station 400
104
201
Communications Transceiver
107
Digital Database
402
Control Panel
403
Keyboard
404
Simulation Port
405
Computer
406
Graphics System
407
Video Display
408
User Flight Controls with Force Feedback
409
Storage Device
410
Video Interface
411
VCR
412
Video Display

Fig. 4



Remote Pilot Station 500
501
Head Mounted Display
502
Head Mounted Display Attitude Sensors
406
Graphics System
408
User Flight Controls with Force Feedback
409
Storage Device
410
Video Interface
411
VCR
412
Video Display
405
Computer
104
201
Communications Transceiver
107
Digital Database
402
Control Panel
403
Keyboard
404
Simulation Port

Fig. 5

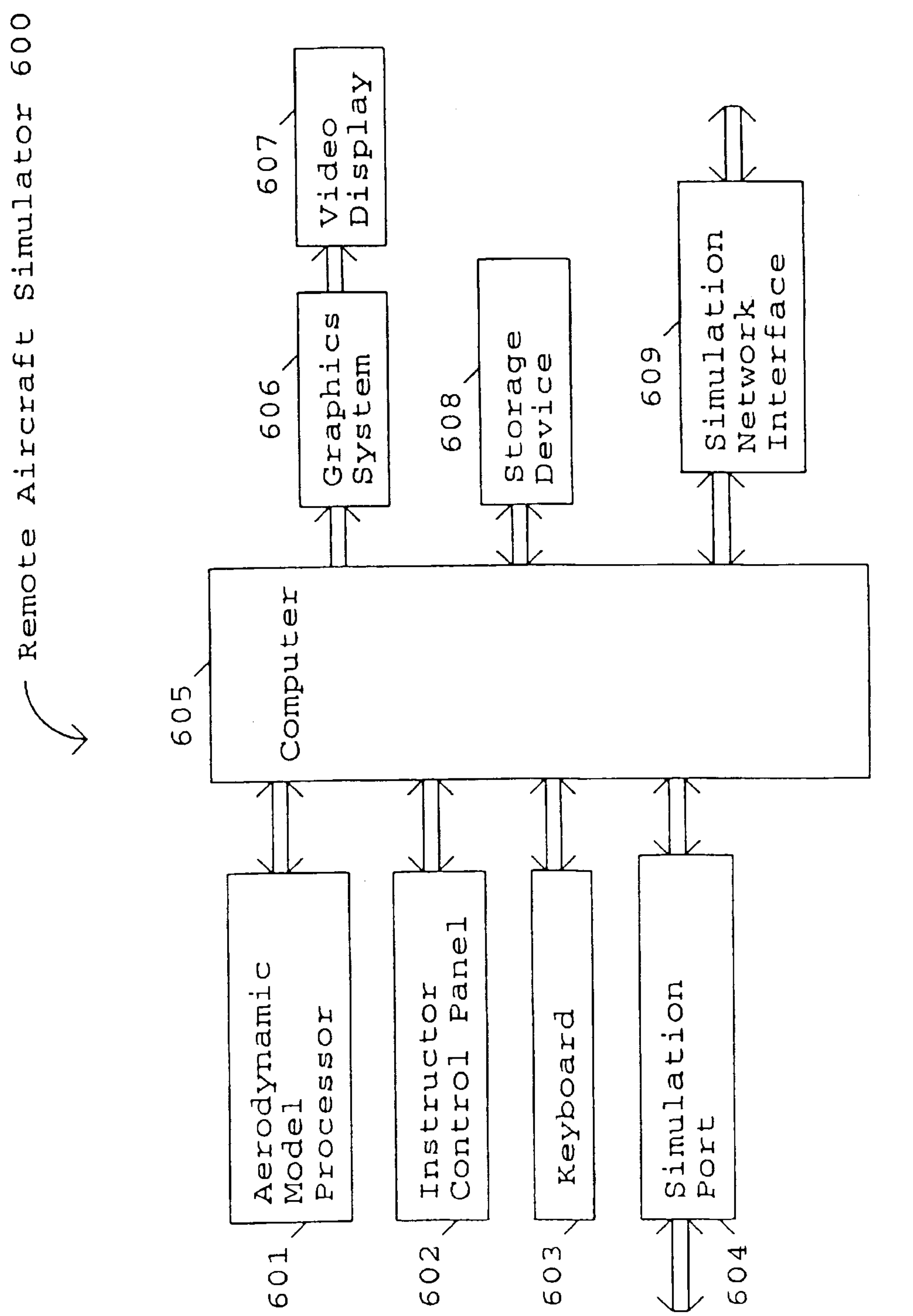

Remote Aircraft Simulator 600
605
Computer
606
Graphics System
607
Video Display
608
Storage Device
609
Simulation Network Interface
Aerodynamic Model Processor
601
Instructor Control Panel
602
Keyboard
603
Simulation Port
604

Fig. 6

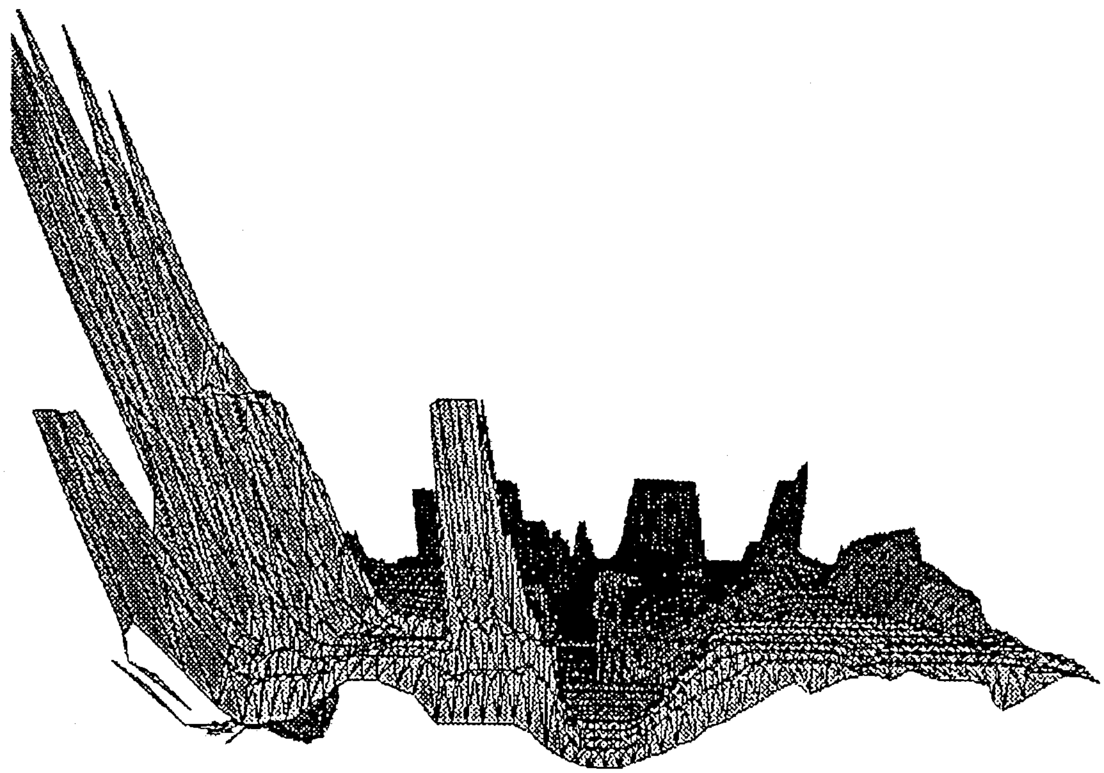


Figure 7

METHOD AND APPARATUS FOR REMOTELY PILOTING AN AIRCRAFT

BACKGROUND OF THE INVENTION—CROSS REFERENCES TO RELATED APPLICATIONS

"Pilot Aid Using a Synthetic Environment", Ser. No. 08/274,394 filed Jul. 11, 1994. "Digital Map Generator and Display System", Ser. No. 08/543,590, filed Oct. 16, 1995.

1. Field of Invention

This invention relates to the field of remotely piloted vehicles (RPVs) and unmanned aerial vehicles (UAVs).

2. Discussion of Prior Art

RPVs can be used for any number of purposes. For example, there is a large organization that promotes the use of remote controlled planes. Certain RPVs are controlled by viewing the plane with the naked eye and using a hand held controller to control its flight Other RPVs are controlled by a remote pilot using simple joysticks while watching the video produced by a camera in the remote aircraft. This camera is also used to produce the reconnaissance video. There are tradeoffs involving the resolution of the video, the rate at which the video is updated, and the bandwidth needed to transmit it. The wider the bandwidth the more difficult it is to secure the signal. The freedom to balance these tradeoffs is limited because this video is also used to pilot the aircraft and must therefore be updated frequently.

Certain UAVs are preprogrammed to follow a predetermined course and lack the flexibility to deal with unexpected situations.

The 1983 patent to Kanaly (U.S. Pat. No. 4,405,943) shows a control and communications system for a remotely piloted vehicle where an oculometer determines where the remote operator is looking and signals the remote vehicle to send the high resolution imagery corresponding to the area around where the remote operator is looking and low resolution imagery corresponding to the remote operator's peripheral vision. The objective is to minimize the bandwidth of the information transmitted to the remote operator.

SUMMARY

A method and apparatus is described that allows a remote aircraft to be controlled by a remotely located pilot who is presented with a synthesized three-dimensional projected view representing the environment around the remote aircraft According to one aspect of the invention, a system is used that includes an aircraft and a remote pilot station.

The aircraft uses a communications link to send its location, attitude, and other operating conditions to the remote pilot station. The remote pilot station receives the data and uses a database describing the terrain and manmade structures in the remote aircraffs environment to produce a 3D view of the remote aircraft environment and present it to the remote human pilot.

The remote pilot responds to the information and manipulates the remote flight controls, whose positions and forces are transmitted to the remote aircraft. Since the amount of data is small, it can be readily secured through encryption and spreadspectrum techniques.

Also, because the video reconnaissance cameras are no longer needed to remotely pilot the aircraft there is great flexibility in their use. To minimize bandwidth and reduce the possibility of being detected, the video data can be sent at a slow update rate. The data can also be stored on the remote aircraft for later transmission. Alternatively, low resolution pictures can be sent in real-time, while the corresponding high resolution pictures can be at a later time. The reconnaissance video can even be transmitted through a different communications link than the control data. There may also be more than one reconnaissance camera.

The delay in the control link must be minimized in order that the remote aircraft can be properly flown. The system can measure the link delay and make this information available to the pilot. This delay link measurement can also be used to modify the control software through which the remote pilot flies the remote aircraft. This is to prevent pilot-induced-oscillation.

The computers in the system allow for several modes of operation. For example, the remote aircraft can be instructed to fly to given coordinates without further input from the remote pilot. It also makes it possible to provide computer assistance to the remote pilot. In this mode, the remote flight control controls absolute pitch and roll angles instead pitch and roll rates which is the normal mode for aircraft In addition, adverse yaw can be automatically corrected so that the resulting control laws make the remote aircraft extremely easy to fly. Because this comes at the expense of being able to put the remote aircraft into unusual attitudes, for complete control of the remote aircraft a standard control mode is provided to give the remote pilot the same type of control that is used to fly a manned aircraft. Since the remote aircraft is unmanned, the remote pilot can subject the remote aircraft to high-G maneuvers that would not be safe for a pilot present in the aircraft.

To facilitate training, a simulated remote aircraft is provided that allows an instructor to set up the training mission and parameters. This is especially useful in giving remote pilots experience flying with different control link delays. In this simulated mode, the system can be further linked to a battlefield simulator such as SIMNET.

In the first embodiment, the remote pilot is provided with a standard video display. Additional display channels can be provided to give the remote pilot a greater field of view. There can even be a display channel to give a rearward facing view.

A second embodiment uses a head mounted display for the remote pilot instead of a standard display. This permits the remote station to be made more compact so that it can be used in a wider variety of installations. An example would be in a manned aircraft flying several hundred miles away.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may best be understood by referring to the following description and accompanying drawings which illustrate the invention. In the drawings:

FIG. 1 is a general illustration showing a remote pilot at a remote pilot station operating a remote aircraft according to one embodiment of the invention.

FIG. 2 is a block diagram showing the communications link between a remote pilot station and a remote aircraft according to one embodiment of the invention.

FIG. 3 is a block diagram of a remote aircraft according to one embodiment of the invention.

FIG. 4 is a block diagram of a remote pilot station according to one embodiment of the invention.

FIG. 5 is a block diagram of a remote pilot station according to another embodiment of the invention.

FIG. 6 is a block diagram of a remote aircraft simulator used for training remote pilots according to one embodiment of the invention.

FIG. 7 is an example of a three dimensional projected image presented to a remote pilot by a remote pilot station according to one embodiment of the invention.

DETAILED DESCRIPTION

In the following description, numerous specific details are set forth to provide a thorough understanding of the invention. However, it is understood that the invention may be practiced without these specific details. In other instances, well-known circuits, structures and techniques have not been shown in detail in order not to obscure the invention.

A method and apparatus is described that allows a remote aircraft to be controlled by a remotely located pilot who is presented with a synthesized three-dimensional projected view representing the environment around the remote aircraft. Since the video from a reconnaissance camera located on the remote aircraft is not used to pilot the remote aircraft, the amount of data transmitted between the remote aircraft and the remote pilot is small. This provides greater flexibility in how the remote aircraft is used and allows the transmitted data to be made more secure. The remote aircraft may be of any type, for example a remote control plane or helicopter as used by recreational enthusiast.

FIG. 1 is a general illustration showing a remote pilot at a remote pilot station operating a remote aircraft according to one embodiment of the invention. FIG. 1 shows Remote Pilot **102** interacting with Remote Pilot Station **101** and controlling Remote Aircraft **103**. Remote Pilot Station **101** and Remote Aircraft **103** respectively include an Antenna **104** and an Antenna **105** for communicating Information **106**.

In one embodiment, Information **106** includes status information concerning the status of Remote Aircraft **103** and flight control information for controlling the flight of Remote Aircraft **103**. The status information is generated by Remote Aircraft **103** and includes the three dimensional position and the orientation (also termed attitude, and comprising heading, roll, pitch) of Remote Aircraft **103**. The status information may also include information concerning the flight surfaces, the engine, an additional altitude reading, etc. Remote Pilot Station **101** uses this status information to retrieve data from a Digital Database **107** which contains a three-dimensional description of terrain and manmade structures over which Remote Aircraft **103** is flying. Based on the three dimensional data retrieved from Digital Database **107**, Remote Pilot Station **101** projects a synthesized three-dimensional projected view of the terrain and manmade structures in the vicinity of Remote Aircraft **103**. Based on this view of the terrain and manmade structures, the Remote Pilot Station **101**, on its own and/or in response to input from Remote Pilot **102**, generates and transmits flight control information to Remote Aircraft **103** which adjusts its flight accordingly.

In one embodiment, the Remote Aircraft **103** is a remote controlled plane or helicopter used for recreational purposes. Since remote controlled planes and helicopters tend to be small in size, the circuitry in such remote aircraft to generate and receive Information **106** is minimized. In such systems, the Remote Pilot Station **101** may be implemented by including additional attachments to an existing portable computer. This allows the user to easily transport the remote aircraft and pilot station to an appropriate location for flight.

FIG. 2 is a block diagram showing a bi-directional communications link between a remote pilot station and a remote aircraft according to one embodiment of the invention. FIG. 2 shows Communications Transceiver **201** coupled to Antenna **104** of Remote Pilot Station **101**, as well as Communications Transceiver **204** coupled to Antenna **105** of Remote Aircraft **103**. In addition, FIG. 2 shows Information **106** being communicated between Antenna **104** and Antenna **105**.

FIG. 3 is a block diagram of a remote aircraft unit used in the remote aircraft according to one embodiment of the invention. FIG. 3 shows Remote Aircraft Unit **300** including Computer **308** coupled to GPS Receiver **301**, Turn-and-bank Indicator **302**, Gyrocompass **303**, Communications Transceiver **204**, Aircraft Engine and Sensors **309**, and Aircraft Flight Surfaces and Sensors **310**. GPS Receiver **301** receives signals from the satellites that make up the global positioning system (GPS) and calculates the aircraft's position in three dimensions. Turn-and-bank Indicator **302** and Gyrocompass **303** provide the aircraft's orientation which comprises heading, roll, and pitch. This data is sent to Computer **308** for transformation into the previously described status information. Computer **308** transmits this status information to Communications Transceiver **204** which produces a radio signal and supplies it to Antenna **105**.

The Aircraft Engine and Sensors **309** are coupled to control the aircraft's engine, while the Aircraft Flight Surfaces and Sensors **310** are coupled to control the aircraft's flight surfaces. The flight control information is received from the remote pilot station by Computer **308** through Antenna **105** and Communications Transceiver **204**. This flight control information is processed by Computer **308** into the necessary signals for transmission to Aircraft Engine and Sensors **309** and Aircraft Flight Surfaces and Sensors **310** to control the aircraft's engine and flight surfaces, respectively. The operation of the aircraft's flight control surfaces will be later described with reference to FIG. 4.

In order to protect against ECM, the communications link between the Remote Pilot Station **101** and the Remote Aircraft **103** may be secured. While any number of different techniques may be used to secure this link, in one embodiment Computer **308** is implemented to encrypttdecrypt the data transmitted and Communications Transceiver **204** is implemented to use spread spectrum techniques.

Computer **308** may optionally be coupled to Altimeter **304**, Video Camera System **305**, Infrared Video Camera System **306**, Radar **307**, and/or Video Storage Unit **311**. Altimeter **304** provides an output of the aircraft's altitude as a safety check in the event GPS Receiver **301** malfunctions. Thus, this additional altitude reading may also be transmitted to Remote Pilot Station **101** as part of the status information.

Video Camera System **305** is controlled by Computer **308** which determines where the camera is pointing as well as focusing and the zoom factor. The video produced by the camera is not used by the remote pilot for flying the remote aircraft, so there is more flexibility in using the video. As a result, any number of techniques can be used for receiving the images captured by Video Camera System **305**. As examples:

1. High resolution, high update images may be sent back in real-time through the Communications Link, when the high bandwidth needed can be tolerated.
2. High resolution, low update images may be sent back in real-time through the Communications Link to reduce the bandwidth.
3. The video may be recorded in Video Storage Unit **311** for later transmission.
4. The video may be transmitted through a separate communications link.
5. There may be multiple video cameras.

Infrared Video Camera System **306** is similar to Video Camera System **305** and has the same operating modes.

Radar **307** in Remote Aircraft **103** may be passive or active. It may scan a particular pattern or it may track a selected object. Radar 307 may consist of several Radar units. The information from Radar 307 is processed by Computer 308 so that only the desired information is transmitted over the communication link to the Remote Pilot Station 101 for display.

FIG. 4 is a block diagram of a remote pilot station according to one embodiment of the invention. FIG. 4 shows a Remote Pilot Station 400 including a Computer 405 coupled to Communications Transceiver 201, Digital Database 107, Graphics System 406, User Flight Controls with Force Feedback 408, and a Storage Device 409. The Storage Device 409 represents one or more mechanisms for storing data. For example, the Storage Device 409 may include read only memory TROM), random access memory (RAM), magnetic disk storage mediums, optical storage mediums, flash memory devices, and/or other machine-readable mediums. Of course, Digital Database 107 may be stored in one or more machine-readable mediums and/or in Storage Device 409.

As previously described, Antenna 104 receives the radio signals transmitted by Remote Aircraft 103 representing the status information of Remote Aircraft 103. These radio signals are transformed by Communications Transceiver 201 and sent to Computer 405. Communications Transceiver 201 is set to the same mode as Communications Transceiver 204, so that if, for example, spread spectrum techniques are used, the signal will be transparently received. Computer 405 recovers the data (de-encrypting, if required) so that the data communications from Computer 308 in the Remote Aircraft to Computer 405 in the Remote Pilot Station is transparent. Thus, the bi-directional communications link comprises the combination of Communications Transceiver 201, Antenna 104, Antenna 105, and Communications Transceiver 204.

As previously described, the status information received by Computer 405 includes the three dimensional position and the orientation of Remote Aircraft 103. The status information may also include information concerning the flight surfaces, flight sensors, the engine, an additional altitude reading, etc. Computer 405 uses this status information to retrieve data from Digital Database 107 which contains a three-dimensional description of terrain and manmade structures over which Remote Aircraft 103 is flying. The composition and creation of the Digital Database 107 is further described later. Based on the three dimensional data retrieved from Digital Database 107, Computer 405 performs the mathematical operations to transform and project the three dimensional data to generate video data representing a synthesized three-dimensional projected view of the terrain (and, if desired, manmade structures) in the vicinity or environment of Remote Aircraft 103. This video data is transmitted to Graphics System 406, which displays the synthesized three-dimensional projected view on Video Display 407.

Since the image is generated from the digital database, virtually any image of the environment of the Remote Aircraft 103 can be generated. As examples, the pilot may select the environment to be: 1) a simulated image of what would be seen out of the cockpit of a manned aircraft on a similar flight path; 3) a simulated image of what would be seen when looking in any direction (e.g., backwards, out a side window, etc.); 3) a simulated image of what would be seen if a camera were tailing the remotely piloted aircraft; etc. In addition, the simulated image may be set to any magnification. Thus, the phrase environment of Remote Aircraft 103 is intended to include any image generated with reference to the remote aircraft's position.

The User Flight controls with Force Feedback 408 are used by the remote pilot to input flight path information. The User Flight Controls may be of any number of different types, some of which are further described later herein. The status information received by Computer 405 also includes information received from Aircraft Flight Surfaces and Sensors 310. This information is used to actuate force feedback circuitry in User Flight Controls With Force Feedback 408. Remote Pilot 102 observes the synthesized three-dimensional environment displayed on Video Display 407, feels the forces on User Flight Controls With Force Feedback 408 and moves the controls accordingly. This flight control information is sent through the communications link to Computer 308, and is used to control the aircraft flight surfaces in Aircraft Flight Surfaces and Sensors 310. Remote Pilot 102 also receives data from Aircraft Engine and Sensors 309 through the communications link and is able to send data back to control the engine.

Flight Control

To illustrate the operation of the remote aircraft, a fixed-wing airplane will be described as an example. However, the basic principles apply to other types of aircraft as well. The basic control surfaces of an airplane consist of the ailerons, the horizontal elevators, and the rudder. The ailerons are moved differentially (one up, one down) to rotate the airplane around its roll axis; the horizontal elevators cause the airplane to rotate around its pitch axis; and the rudder causes the airplane to rotate around its yaw axis.

When the ailerons are used to modify the lift characteristics of the wings, one wing creates more lift while the other wing creates less lift. This also changes the drag characteristics of the wings and results in a yaw force that is opposite to the yaw force that results from the tail section causing the airplane to weather-cock into the relative wind. It is this yaw force caused by the airplane weather-cocking into the relative wind that causes a banked airplane to turn. The opposite yaw force produced by using the ailerons is called adverse yaw; the rudder control is used to counteract this force to produce a coordinated turn.

The simplest type of flight control consists of a joystick and a set of rudder pedals. The controls are directly connected to the flight control surfaces. With a joystick, moving the stick left and right moves the ailerons, while moving the stick forward and backward moves the horizontal elevators. The rudder is controlled by two foot pedals, one for each foot, that are mounted on a common shaft and hinged in the middle like a seesaw. Pressing one foot pedal forward causes the other foot pedal to move backward and causes the rudder to also move in one direction. Pressing the other foot pedal causes it to move forward and the opposite pedal to move backward and causes the rudder to move in the opposite direction.

An alternative to the joystick is the control yoke which consists of a wheel attached to a shaft that moves in and out of the control housing. Turning the wheel clockwise or counterclockwise moves the ailerons; moving the wheel shaft in and out moves the horizontal elevators. The rudder pedals as the same as those used with a joystick.

In order to aid in a description of remote aircraft operation, it is thought worthwhile to first describe the operation of non-remotely piloted vehicles. Non-remotely piloted vehicles can be operated in one of two ways (also termed as flight control modes); direct control or computer control (also termed as computer mediated).

Direct Control Non-Remotely Piloted Vehicles

When the flight controls are connected directly to the control surfaces the result is a second order system. Using

the joystick as an example, moving the joystick left or right establishes a roll rate. The airplane continues to roll until the joystick is returned to the center position, after which the airplane remains in the bank angle thus established. The foot pedals are used to counteract the adverse yaw as previously described. Moving the joystick forward or backward establishes a pitch rate. The airplane continues to pitch until the joystick is returned to the center position, after which the airplane remains in the pitch angle thus established. Both the roll rate and the pitch rate are subject to the limits of the airplane's design.

Since the joystick is directly connected to the control surfaces, the aerodynamic forces on the control surfaces are transmitted back to the pilot, giving him or her valuable feedback on how the airplane is flying.

The successful operation of the second order system with the pilot in the loop depends on several factors such as the area and placement of the control surfaces, how much the control surfaces move in response to the movement of the pilot controls, and how long the airplane takes to respond to changes of the control surfaces. The total system characteristics also depend on the reaction time of the pilot. If the resulting system is poorly designed it may be unstable, which means it may not be possible for a human pilot to fly it safely. An example of an unstable system is where the pilot desires to perform a gentle roll to the right and so moves the joystick to the right, the airplane's roll rate is faster than the pilot desires so he/she attempts to compensate by moving the joystick to the left, the airplane rolls left at a rate that is faster than the pilot desires so he/she moves the joystick to the right, and so on, with the pilot constantly overcorrecting and with the aircraft's rolling motions constantly getting larger and larger until the aircraft gets into a condition from which it may not be possible to recover, (e.g., spinning into the ground). The type of loss of control described is usually referred to as 'pilot induced oscillation' and although it may be caused by an inexperienced or inattentive pilot, it is more often caused by poor airplane design. Therefore, new airplane designs are extensively tested to make sure they can be safely flown. Examples of airplanes that use direct control of the control surfaces (Direct Control Second Order Systems) are the Cessna 150 and the Piper Cub.

Computer Mediated Non-Remotely Piloted Vehicles

Computer mediated control systems use a computer between the pilot controls and the control surfaces. The pilot controls are read by the computer, the data are modified in a particular way, and the computer sends control signals to the control surfaces. The computer may also sense the forces on the control surface and use it to control force feedback to the pilot controls. This type of computer mediated control may be used to fly an airplane that would otherwise be unstable, such as the F16 or the F117. Aircraft such as the F16 and F117 are also second order systems because the position of the pilot's joystick represents rate of rotation.

There are risks inherent in a computer mediated system. Although the program can be simulated extensively before using it in an actual airplane, the computer program may be quite large and therefore difficult to simulate under all possible conditions. An example of this is the Swedish JAS 39 Gripen Fighter. Despite extensive simulation of the flight control system, during a test flight a Gripen crashed due to "... the flight control system's high amplification of stick commands combined with the pilot's" large, rapid stick movements"." The pilot had entered a low-speed high-banked turn at a 280 meter altitude with lit afterburners and

was leaving the turn when his actions led to 'pilot-induced oscillation'. (Aviation Week & Space Technology, Aug. 23, 1993, pages 72–73).

Having described techniques for operating non-remotely piloted vehicles, the Fight Control Modes for RPVs will be described.

Second Order RPV Flight Control Mode

A second order control system for an RPV is inherently computer mediated because the remote pilot must interact through two computers: the computer in the remote aircraft and the computer in the remote pilot station.

Flying an RPV is further complicated because there are additional time delays in the loop. The computer in the remote aircraft must first determine the aircraft's position and orientation. The additional processing for transmitting a secure signal by encryption and/or spread spectrum techniques may create additional delays. Transmission delay of signals between the remote aircraft and remote pilot station is negligible for a direct path. However, if the signals are relayed through other facilities the delay time may be appreciable, especially if an orbiting satellite is used. There are additional delays in the remote pilot station as the remote aircraft's position and orientation are used to transform the data from the digital database to present the pilot with the synthesized 3D projected view from the remote aircraft. In one embodiment, the RPV system measures the various delays and modifies the control laws used by the computer in the remote pilot aircraft and in the feedback provided by the computer in the remote pilot station to the remote pilot. For example, the computer may adjust the sensitivity of the User Flight Controls **408** according to the delay (e.g., as the delay increases, the computer will decrease the sensitivity of the flight controls). The system also displays the measured delay to the remote pilot.

First Order RPV Flight Control Mode

The stability of the flight control system, and thus the flyability of an RPV, can be improved considerably by using a first order system. In one embodiment of such a first order system the position of the remote pilot's joystick represents an angle relative to the horizon, instead of representing a rate of rotation as in a second order system. The position of the joystick is transmitted to the computer in the remote aircraft which moves the control surfaces as required to place the remote aircraft in the requested orientation. The control system in the remote aircraft is still a second order system but the delays in the communications link and the remote pilot station are no longer a part of the system's loop.

When a joystick is centered, the remote aircraft will fly straight and level. When the joystick is to the right of center the remote aircraft will be in a right banked turn. When the joystick is to the left of center the remote aircraft will be in a left banked turn. When the joystick is backward from center the remote aircraft will be in a pitch up orientation. When the joystick is forward of center the remote aircraft will be in a pitch down orientation.

The amount of bank and pitch permitted depends on the design of the remote aircraft. A high performance remote aircraft will be capable of a greater amount of pitch and bank than will a low performance remote aircraft.

Referring again to FIG. **4**, Computer **405** may optionally be coupled to Control Panel **402**, Keyboard **403**, Simulation Port **404**, Video Interface **410**, VCR **411**, and/or Video Display **412**. In one embodiment, Control Panel **402** con-

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tains specialized lights, displays, and switches to allow a quicker response to situations than can be provided by Keyboard **403**. Control Panel **402** can be arranged to approximate the look and feel of an actual aircraft cockpit. Keyboard **403** allows the remote pilot to select various operating modes. For training purposes, Simulation Port **404** allows the remote pilot station to be connected to a remote aircraft simulator instead of an actual remote aircraft. The remote aircraft simulator will be further described with reference to FIG. **6**. Storage Device **409** allows the flight data to be recorded. During playback this previously recorded data is substituted for real-time data from the remote aircraft to replay the mission for analysis. Any video received from any reconnaissance cameras on the Remote Aircraft **103** is converted by Video Interface **410** so that it can be recorded on VCR **411** and displayed on Video Display **412**. VCR **411** can also operate in straight-through mode so that the reconnaissance video can be viewed in real time.

FIG. **5** is a block diagram of a remote pilot station according to another embodiment of the invention. FIG. **5** shows Remote Pilot Station **500**. Remote Pilot Station **500** is similar to Remote Pilot Station **400** of FIG. **4**, except Video Display **407** is replaced by Head Mounted Display **501**. In addition, Head Mounted Display Attitude Sensors **502** are coupled to Computer **405**. Head Mounted Display Attitude Sensors **502** measure the attitude of Head Mounted Display **501**. This information is used by Computer **405** to produce an additional three dimensional transformation of the data from Digital Database **107** to account for the attitude of the remote pilots Head Mounted Display **501**. This does not require any additional data from the remote aircraft. Of course, alternative embodiments could include both a video display and a head mounted display.

FIG. **6** is a block diagram of a simulated remote aircraft used for training remote pilots according to one embodiment of the invention. FIG. **6** shows Remote Aircraft Simulator **600** including Computer **605** coupled to Aerodynamic Model Processor **601**, Instructor Control Panel **602**, Keyboard **603**, Simulation Port **604**, Graphics System **606**, Storage Device **608**, and Simulation Network Interface **609**. Remote Aircraft Simulator **600** communicates with Remote Pilot Station **400** or **500** through Simulation Port **604**. Aerodynamic Model Processor **601** executes a mathematical model that simulates the behavior of a remote aircraft. An instructor uses Instructor Control Panel **602** and Keyboard **603** to select various training scenarios. Graphics System **606** and Video Display **607** are used to observe the operation of the system. Storage Device **608** is used to record the training session for later evaluation of the session. In addition to proficiency training, the Remote Aircraft Simulator can also be used to practice a proposed mission. The data communicated to the remote pilot station can include training and evaluation data for processing and/or display. This training and evaluation data can include any relevant information, such as flight path accuracy, etc.

Simulation Network Interface **609** permits participation in a battlefield simulation system such as SIMNET, mixing aircraft, tanks, and ground troops for training in the coordination of mixed forces. Thus, the system is designed to allow for the communication of this battlefield simulation information between the remote aircraft simulator and the remote pilot station. This allows the remote pilot station to display one or more other simulated entities (e.g., tanks, ground troops, other aircraft, etc.) described by the battlefield simulation information.

The Database

The Digital Database **107** can be comprised of any type of data from which a three dimensional image can be generated. For example, 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.

The other USGS database 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 the remote pilot can select them to be highlighted by category or by specific object.

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

The procedure for generating the synthesized three-dimensional view from the Digital Database may use any number of techniques, including those disclosed in the 1987 patent to Beckwith et al. (U.S. Pat. No. 4,660,157 REAL TIME VIDEO PERSPECTIVE DIGITAL MAP DISPLAY METHOD), and the 1993 patent to Dawson et al. (U.S. Pat. No. 5,179,638 METHOD AND APPARATUS FOR GENERATING A TEXTURE MAPPED PERSPECTIVE VIEW). One disadvantage of generating the synthesized three-dimensional view from these elevation databases in real time is the amount of storage space they require. To avoid this large amount of data storage, one embodiment of Digital Database **107** is composed of terrain data that represents the real terrain using polygons. This database may be generated using any number of techniques. For example, this database may be generated by transforming one or more elevation databases into a polygon database using the technique taught in "Pilot Aid Using a Synthetic Environment", Ser. No. 08/274,394 filed Jul. 11, 1994. Another method for transforming one or more elevation databases into a polygon database is taught in "Digital Map Generator and Display System", Ser. No. 08/543,590, filed Oct. 16, 1995. An example of a three dimensional projected image created from this database is shown in FIG. **7**.

While the invention has been described in terms of several embodiments, those skilled in the art will recognize that the invention is not limited to the embodiments described. The method and apparatus of the invention can be practiced with modification and alteration within the spirit and scope of the appended claims. The description is thus to be regarded as illustrative instead of limiting on the invention.

What is claimed is:

1. A system comprising:
   - a remotely piloted aircraft including,
     - a position determining system to locate said remotely piloted aircraft's position in three dimensions; and
     - an orientation determining system for determining said remotely piloted aircraft's orientation in three dimensional space;
   - a communications system for communicating flight data between a computer and said remotely piloted aircraft,

said flight data including said remotely piloted aircraft's position and orientation, said flight data also including flight control information for controlling said remotely piloted aircraft;

a digital database comprising terrain data;

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

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

a set of one or more remote flight controls coupled to said computer for inputting said flight control information, wherein said computer is also for determining a delay time for communicating said flight data between said computer and said remotely piloted aircraft, and wherein said computer adjusts the sensitivity of said set of one or more remote flight controls based on said delay time.

2. The system of claim 1, wherein:

said remotely piloted aircraft includes a device for capturing image data; and

said system operates in at least a first mode in which said image data is not transmitted from said remotely piloted aircraft to said computer at a sufficient data rate to allow for real time piloting of the remotely piloted aircraft.

3. The system of claim 1, wherein the flight data communicated between said remotely piloted aircraft and said computer is secured.

4. The system of claim 1, wherein said remotely piloted aircraft further comprises a set of one or more video cameras.

5. The system of claim 4, wherein said communications system is also for communicating video data representing images captured by said set of one or more video cameras, said video data for displaying said images.

6. The system of claim 5, wherein said video data is transmitted on a different communication link than said flight data.

7. The system of claim 4, wherein at least one camera in said set of one or more video cameras is an infrared camera.

8. The system of claim 1, wherein said display is a head mounted display.

9. The system of claim 1, wherein said set of one or more remote flight controls is responsive to manual manipulations.

10. The system of claim 1, wherein said set of one or more remote flight controls allows for inputting absolute pitch and roll angles instead of pitch and roll rates.

11. The system of claim 1, wherein said computer is also used for correcting adverse yaw without requiring input from said set of one or more remote flight controls.

12. The system of claim 1, wherein:

said remotely piloted aircraft includes a device for capturing image data; and said system operates in at least a first mode in which said image data is not transmitted from said remotely piloted craft to said computer but stored in said remotely piloted aircraft.

13. A station for flying a remotely piloted aircraft that is real or simulated comprising:

a database comprising terrain data;

a set of remote flight controls for inputting flight control information;

a computer having a communications unit configured to receive status information identifying said remotely piloted aircraft's position and orientation in three dimensional space, said computer configured to access said terrain data according to said status information and configured to transform said terrain data to provide three dimensional projected image data representing said remotely piloted aircraft's environment, said computer coupled to said set of remote flight controls and said communications unit for transmitting said flight control information to control said remotely piloted aircraft, said computer also to determine a delay time for communicating said flight control information between said computer and said remotely piloted aircraft, and said computer to adjust the sensitivity of said set of remote flight controls based on said delay time; and

a display configured to display said three dimensional projected image data.

14. The station of claim 13, wherein said communications unit is also configured to receive video data representing images captured by a set of video cameras on said remotely piloted aircraft, said video data for displaying said images.

15. The station of claim 14, wherein said video data is transmitted on a different communication link that said flight control information and said status information.

16. The station of claim 13, wherein said display is a head mounted display.

17. The station of claim 13, wherein said set of remote flight controls is responsive to manual manipulations.

18. The station of claim 13, wherein said set of remote flight controls are configured to allow inputting absolute pitch and roll angles instead of pitch and roll rates.

19. The station of claim 13, wherein said computer is also configured to correct adverse yaw without requiring input from said set of remote flight controls.

20. The station of claim 13, wherein said communications unit includes at least one of a communications transceiver and a simulation port.

* * * * *

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IN THE UNITED STATES DISTRICT COURT

FOR THE DISTRICT OF ARIZONA

UNIVERSAL AVIONICS SYSTEMS CORPORATION, Plaintiff, v. OPTIMA TECHNOLOGY GROUP, INC., OPTIMA TECHNOLOGY CORPORATION and JED MARGOLIN, Defendants.	Case No. CV-00588-RC **SECOND AMENDED COMPLAINT** [JURY TRIAL DEMANDED]

Plaintiff Universal Avionics Systems Corporation ("Universal"), by and through its undersigned attorneys, for their Second Amended Complaint against Defendants Optima Technology Group, Inc. ("OTG"), Optima Technology Corporation ("OTC") and Jed Margolin ("Margolin") (collectively, "Defendants") alleges as follows based upon its best available information and belief. Defendant OTG is an entity commonly referred to as a patent holding company. In simple terms, Defendants OTG, its President and CEO Robert Adams ("Adams"), and Margolin, made repeated and baseless threats to Universal regarding several patents purportedly owned by OTG. No longer willing to be subjected

James Burdett
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to meritless allegations and countless threats, Universal initiated the present action.

NATURE OF THE ACTION

1. This is an action seeking a declaratory judgment that U.S. Patent Nos. 5,566,073 (the "'073 patent") and 5,904,724 (the "'724 patent") (collectively, the "Patents-in-Suit") are invalid and not infringed.

THE PARTIES

2. Plaintiff Universal is an Arizona corporation, having a principal place of business at 3260 East Universal Way, Tucson, Arizona 85706.

3. Upon information and belief, Defendant Optima Technology Group, Inc. is a Delaware corporation, having a principal place of business at 1981 Empire Road, Reno, Nevada 89521.

4. Upon information and belief, Defendant Optima Technology Corporation is a California corporation, having a principal place of business at 2222 Michelson Drive, Suite 1830, Irvine, California 92612.

5. Upon information and belief, Defendant Margolin resides at 1981 Empire Road, Reno, Nevada 89521.

JURISDICTION AND VENUE

6. This is an action seeking a declaratory judgment that the '073 patent and the '724 patent are invalid and not infringed.

7. This Court has original jurisdiction over this action pursuant to the Federal Declaratory Judgment Act, 28 U.S.C. §§ 2201-2202, the Patent Laws of the United States, 35 U.S.C. §100 et seq. and 28 U.S.C. §§ 1331, 1332 and 1338(a) and (b).

8. Venue is proper in this judicial district because Defendants have engaged in business dealings with Plaintiff Universal in this judicial district. *See* 28 U.S.C. § 1391.

9. Additionally, Defendants OTG and Margolin have not objected to the jurisdiction of this Court or that venue is proper.

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THE PATENTS-IN-SUIT

10. On October 15, 1996, the United States Patent and Trademark Office ("PTO") issued United States Patent No. 5,566,073, entitled "Pilot Aid Using a Synthetic Environment." A copy of the '073 patent is attached as Exhibit 1 to the original Complaint. Defendant Margolin is the named inventor on the face of the '073 patent.

11. On May 18, 1999, the PTO issued United States Patent No. 5,904,724, entitled "Method and Apparatus for Remotely Piloting an Aircraft." A copy of the '724 patent is attached as Exhibit 2 to the original Complaint. Defendant Margolin is the named inventor on the face of the '724 patent.

12. Upon information and belief, on or about July 20, 2004, Margolin executed a Durable Power of Attorney (attached as Exhibit 3 to the original Complaint), whereby he appointed "Optima Technology Inc. - Robert Adams, CEO" as his agent with the "powers to manage, dispose of, sell and convey" various issued patents, including the '073 and '724 patents. The Durable Power of Attorney was directed to the registered address for OTC.

13. Upon information and belief, on or about December 5, 2007, Defendant OTC filed a notice of recordation of assignment with the PTO, indicating that Margolin had assigned four patents, including the '073 and '724 patents, to it. (Attached as Exhibit 1 to the First Amended Complaint).

FACTS - OTG and Margolin

14. On or about July 3, 2007, Adams contacted Universal's outside legal counsel and advised that OTG had become aware of Universal's patent infringement litigation with Honeywell International Inc. and Honeywell Intellectual Properties Inc. (collectively, "Honeywell"), then pending in the District Court of Delaware. Specifically, Adams suggested that OTG could "help [Universal] with said case using our patents to make [Honeywell] back off on their case" because, according to Adams, Honeywell

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infringes the Patents-in-Suit. (Attached as Exhibit 4 to the original Complaint).

15. Adams suggested that Universal should either purchase or accept a license under the Patents-in-Suit in order to assert it against Honeywell. That communication also contained an email from Margolin in which he suggested that Universal "could get some leverage against Honeywell . . . by buying '073 and/or taking an exclusive license from us and then nail Honeywell who also infringes [the '073 patent]." (Attached as Exhibit 5 to the original Complaint).

16. Universal's counsel responded to Adams the same day, informing Adams that an analysis was necessary prior to considering OTG's license offer.

17. Despite Adams' initial suggestion that the overture was intended to "help" Universal in an action against Honeywell, he almost immediately began asserting that Universal was also infringing the Patents-in-Suit. (*Id.*)

18. On or about July 16, 2007, Adams began to issue not-so-subtle threats against Universal, suggesting that OTG would grant a license under the Patents-in-Suit to Honeywell -- so that Honeywell could sue Universal -- should Universal decline OTG's offer. "Seeing that both your client [Universal] and Honeywell infringes, it might be a good thing for your client to take the exclusive license now that your case turned, before of course Honeywell takes the opportunity to do the same thing and use it against others." (*Id.*)

19. Adams continued his threats against Universal in an August 7, 2007 email in which he claimed that OTG had decided on a law firm "in the event that I need to hire them to take on Honeywell, Mercury Computer Systems as well as all the others." (Attached as Exhibit 6 to the original Complaint).

20. On or about August 10, 2007, Universal responded to the August 7, 2007 email, informing Adams that counsel would be speaking to Universal's management in the coming week to discuss OTG's license offer. Adams apparently was satisfied by this

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response, as he retreated from his threats and returned to discussing the possibility of Universal and OTG cooperating and entering into a "working relationship." Specifically, Adams opined that "[o]ur working models show that not only would [the Patents-in-Suit] make Honeywell back-off their case against your client [Universal], but your client will be in a key position to go after approximately $56 Million and growing in business that Honeywell infringes. A win win for both of us . . . ." (Attached as Exhibit 7 to the original Complaint).

21. On or about August 15, 2007, Universal and Adams agreed to meet in an effort to resolve the dispute. The meeting was scheduled for September 11, 2007 at Universal's corporate headquarters in Tucson, Arizona (the "Tucson Meeting"). In anticipation of the Tucson Meeting, on or about August 22, 2007, Universal and OTG entered into a Confidential, Nondisclosure and Limited Use Agreement. (Attached as Exhibit 8 to the original Complaint).

22. The purpose of the Tucson Meeting was to hear and consider economic issues surrounding OTG's offer to license the Patents-in-Suit in an effort to avoid further threats, nuisance and wasted money and time. Universal was represented at the Tucson Meeting by several members of senior management, along with its outside legal counsel. Adams was the sole representative for OTG and gave the impression that he was acting on behalf of both OTG and Margolin.

23. At the meeting, Universal made it clear that (1) a license to the Patents-in-Suit was unnecessary because Universal did not sell any products covered by any claim from the '073 or '724 patents; and (2) Universal believed that the '073 and '724 patents were invalid based on several prior art references. In response, Adams stated that he would have to defer to his legal counsel as he did not know anything about patent validity. Universal repeatedly asked Adams to identify terms he considered appropriate for a settlement but he refused to provide any specific terms. Instead, Adams claimed that

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several unnamed parties had already entered into license agreements with OTG in connection with the Patents-in-Suit and an agreement with Universal would need to be on similar terms. However, Adams refused to disclose the terms of the "mystery" agreements.

24. At the Tucson Meeting, Adams also (mis)represented that OTG had been involved in a number of successful patent infringement lawsuits in the past. By implication, he suggested that if Universal failed to settle on terms acceptable to the Defendants, it would be the next litigation target. However, upon information and belief, Defendant OTC previously filed only one (1) patent litigation involving unrelated technology -- which it lost -- while OTG has not filed any.

25. Adams concluded the meeting by providing contact information for Defendant Margolin and inviting Universal to contact Margolin to seek additional information.

26. After apparently realizing that it was unlikely that Universal and OTG would agree on terms for an agreement, Adams again resorted to threatening Universal. First, he suggested (again) that OTG would enter into a license with Honeywell so that Honeywell could sue Universal. "Not a problem, I am sure Honeywell will be more then [sic] pleased to talk with us and take the exclusive [if] anything just into [sic] enforce it against others whom they know will [sic] from past infringement case." (Attached as Exhibit 14 to the original Complaint). Universal did not take the bait.

27. Adams then got hostile, falsely accusing Universal's President of "stealing our patented concept some time ago and [claiming to have] the web traffic to prove it was at the very least his company and/or his personal IP address." (Attached as Exhibit 15 to the original Complaint).

28. Then, on October 15, 2007, Adams notified Universal of an alleged offer made by Honeywell and stated that Universal has "four hours from now . . . to accept and

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make us a better offer or decline by not responding." (Attached as Exhibit 16 to the original Complaint).

29. Finally, on November 6, 2007, OTG's outside counsel, M. Lawrence Oliverio ("Oliverio") of Rissman Jobse Hendricks & Oliverio,[1] sent counsel for Universal a letter specifically threatening litigation. (Attached as Exhibit 17 to the original Complaint).

30. Based upon the specific allegations of infringement contained in Oliverio's November 6, 2007 letter, Universal had a reasonable apprehension that OTG will file suit for alleged infringement of the '073 and '724 patents.

FACTS - OTC

31. Upon information and belief, Adams, OTG's current President and CEO, was a paid employee of Defendant OTC from 1990-1995 and its unpaid CEO from 2001 to 2005.

32. The Durable Power of Attorney (attached as Exhibit 3 to the original Complaint) that Margolin executed on July 20, 2004, whereby he appointed "Optima Technology Inc. - Robert Adams, CEO" as his agent, was entered into during Adams' tenure as OTC's CEO. Additionally, the Durable Power of Attorney provided the following address for Optima Technology Inc.: 2222 Michelson, Suite 1830, Irvine, California 92612 -- the registered address for Defendant OTC.

33. Upon information and belief, on or about December 5, 2007, Defendant OTC filed a notice of recordation of assignment with the PTO, indicating that Margolin had assigned four patents, including the '073 and '724 patents, to OTC. (Attached as Exhibit 1 to the First Amended Complaint).

34. Upon information and belief, on or about December 19, 2007, Margolin

[1] Despite repeatedly identifying himself as OTG's outside counsel, Mr. Oliverio has subsequently advised Universal's outside counsel that he no longer represents OTG, Adams or Margolin.

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terminated the Durable Power of Attorney -- two weeks after OTC had filed the notice of recordation of assignment with the PTO.

35. Upon information and belief, at some point between September 21, 2007 and October 5, 2007, Margolin created a Patent Assignment which he knowingly and fraudulently back-dated to July 20, 2004, whereby he attempted to assign the entire right, title and interest in the '073 and '724 patents to OTG. (Attached as Exhibit 2 to the First Amended Complaint).

CLAIMS FOR RELIEF

COUNT ONE

Declaratory Judgment of Non-Infringement of the '073 Patent against OTG and/or Margolin

36. Universal repeats and realleges the allegations above as if fully set forth herein.

37. As set forth in Paragraph 29 above, on November 6, 2007, OTG, through its outside counsel, sent a threatening letter to Universal's outside counsel, accusing Universal of infringing the '073 and '724 patents with respect to Universal's Vision-1, UNS-1 and TAWS products. Furthermore, as indicated in Paragraph 29 above, OTG suggested that it was likely to file a litigation if Universal was unwilling to accede to unreasonable licensing demands by November 11, 2007. Accordingly, an actual and continuing controversy has arisen and continues to exist between OTG, on the one hand, and Universal, on the other hand, as to whether or not Universal has directly infringed, contributed to the infringement of, or induced the infringement of, any valid and/or enforceable claim of the '073 patent.

38. Universal has not infringed and is not now infringing, contributorily infringing or inducing infringement of any valid and/or enforceable claim of the '073 patent, either literally or under the doctrine of equivalents.

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39. Accordingly, Universal requests a declaration from this Court that Universal has not infringed and is not now infringing, contributorily infringing or inducing infringement of any valid and/or enforceable claim of the '073 patent, either literally or under the doctrine of equivalents.

COUNT TWO

Declaratory Judgment of Invalidity of the '073 Patent against OTG and/or Margolin

40. Universal repeats and realleges the allegations above as if fully set forth herein.

41. As set forth in Paragraph 29 above, on November 6, 2007, OTG contacted Universal's outside counsel and accused Universal of infringing the '073 patent. Furthermore, as indicated in Paragraph 29 above, OTG suggested that it was likely to file a litigation if Universal was unwilling to accede to unreasonable licensing demands by November 11, 2007. Accordingly, an actual and continuing controversy has arisen and continues to exist between OTG and Universal as to the validity of each of the claims of the '073 patent.

42. Upon information and belief, the '073 patent, and each of the claims thereof, are invalid and void for failure to meet the conditions of patentability as set forth in the provisions of the Patent Laws, 35 U.S.C. §§ 100 et. seq., including but not limited to, one or more of 35 U.S.C. §§ 101, 102, 103 and/or 112.

43. Accordingly, Universal requests a declaration from this Court that each of the claims of the '073 patent is invalid for failure to comply with the provisions of the Patent Laws, 35 U.S.C. §§ 100 et. seq., including but not limited to, one or more of 35 U.S.C. §§ 101, 102, 103 and/or 112.

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COUNT THREE

Declaratory Judgment of Non-Infringement of the '724 Patent against OTG and/or Margolin

44. Universal repeats and realleges the allegations above as if fully set forth herein.

45. As set forth in Paragraph 29 above, on November 6, 2007, OTG, through its outside counsel, sent a threatening letter to Universal's outside counsel, accusing Universal of infringing the '073 and '724 patents with respect to Universal's Vision-1, UNS-1 and TAWS products. Furthermore, as indicated in Paragraph 29 above, OTG suggested that it was likely to file a litigation if Universal was unwilling to accede to unreasonable licensing demands by November 11, 2007. Accordingly, an actual and continuing controversy has arisen and continues to exist between OTG, on the one hand, and Universal, on the other hand, as to whether or not Universal has directly infringed, contributed to the infringement of, or induced the infringement of, any valid and/or enforceable claim of the '724 patent.

46. Universal has not infringed and is not now infringing, contributorily infringing or inducing infringement of any valid and/or enforceable claim of the '724 patent, either literally or under the doctrine of equivalents.

47. Accordingly, Universal requests a declaration from this Court that Universal has not infringed and is not now infringing, contributorily infringing or inducing infringement of any valid and/or enforceable claim of the '724 patent, either literally or under the doctrine of equivalents.

COUNT FOUR

Declaratory Judgment of Invalidity of the '724 Patent against OTG and/or Margolin

48. Universal repeats and realleges the allegations above as if fully set forth herein.

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49. As set forth in Paragraph 29 above, on November 6, 2007, OTG contacted Universal's outside counsel and accused Universal of infringing the '724 patent. Furthermore, as indicated in Paragraph 29 above, OTG suggested that it was likely to file a litigation if Universal was unwilling to accede to unreasonable licensing demands by November 11, 2007. Accordingly, an actual and continuing controversy has arisen and continues to exist between OTG and Universal as to the validity of each of the claims of the '724 patent.

50. Upon information and belief, the '724 patent, and each of the claims thereof, are invalid and void for failure to meet the conditions of patentability as set forth in the provisions of the Patent Laws, 35 U.S.C. §§ 100 et. seq., including but not limited to, one or more of 35 U.S.C. §§ 101, 102, 103 and/or 112.

51. Accordingly, Universal requests a declaration from this Court that each of the claims of the '724 patent is invalid for failure to comply with the provisions of the Patent Laws, 35 U.S.C. §§ 100 et. seq., including but not limited to, one or more of 35 U.S.C. §§ 101, 102, 103 and/or 112.

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COUNT FIVE

Declaratory Judgment of Non-Infringement of the '073 Patent against OTC

52. Universal repeats and realleges the allegations above as if fully set forth herein.

53. Universal has not infringed and is not now infringing, contributorily infringing or inducing infringement of any valid and/or enforceable claim of the '073 patent, either literally or under the doctrine of equivalents.

54. Accordingly, Universal requests a declaration from this Court that Universal has not infringed and is not now infringing, contributorily infringing or inducing infringement of any valid and/or enforceable claim of the '073 patent, either literally or under the doctrine of equivalents.

COUNT SIX

Declaratory Judgment of Invalidity of the '073 Patent against OTC

55. Universal repeats and realleges the allegations above as if fully set forth herein.

56. Upon information and belief, the '073 patent, and each of the claims thereof, are invalid and void for failure to meet the conditions of patentability as set forth in the provisions of the Patent Laws, 35 U.S.C. §§ 100 et. seq., including but not limited to, one or more of 35 U.S.C. §§ 101, 102, 103 and/or 112.

57. Accordingly, Universal requests a declaration from this Court that each of the claims of the '073 patent is invalid for failure to comply with the provisions of the Patent Laws, 35 U.S.C. §§ 100 et. seq., including but not limited to, one or more of 35 U.S.C. §§ 101, 102, 103 and/or 112.

COUNT SEVEN

Declaratory Judgment of Non-Infringement of the '724 Patent against OTC

58. Universal repeats and realleges the allegations above as if fully set forth herein.

59. Universal has not infringed and is not now infringing, contributorily infringing or inducing infringement of any valid and/or enforceable claim of the '724 patent, either literally or under the doctrine of equivalents.

60. Accordingly, Universal requests a declaration from this Court that Universal has not infringed and is not now infringing, contributorily infringing or inducing infringement of any valid and/or enforceable claim of the '724 patent, either literally or under the doctrine of equivalents.

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COUNT EIGHT

Declaratory Judgment of Invalidity of the '724 Patent against OTC

61. Universal repeats and realleges the allegations above as if fully set forth herein.

62. Upon information and belief, the '724 patent, and each of the claims thereof, are invalid and void for failure to meet the conditions of patentability as set forth in the provisions of the Patent Laws, 35 U.S.C. §§ 100 et. seq., including but not limited to, one or more of 35 U.S.C. §§ 101, 102, 103 and/or 112.

63. Accordingly, Universal requests a declaration from this Court that each of the claims of the '724 patent is invalid for failure to comply with the provisions of the Patent Laws, 35 U.S.C. §§ 100 et. seq., including but not limited to, one or more of 35 U.S.C. §§ 101, 102, 103 and/or 112.

PRAYER FOR RELIEF

WHEREFORE, Plaintiff respectfully requests that this Court enter judgment in its favor and grant the following relief:

A. An order and judgment declaring that Universal does not infringe any valid and enforceable claim of the '073 patent;

B. An order and judgment declaring that the claims of the '073 patent are invalid and/or unenforceable;

C. An order and judgment declaring that Universal does not infringe any valid and enforceable claim of the '724 patent;

D. An order and judgment declaring that the claims of the '724 patent are invalid and/or unenforceable;

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E. An order and judgment that this is an exceptional case, pursuant to 35 U.S.C. § 285, and awarding reasonable attorneys' fees and costs.

DATED this 15th day of July 2008.

GREENBERG TRAURIG, LLP

By: /s/ Scott J. Bornstein

E. Jeffrey Walsh
GREENBERG TRAURIG, LLP
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CERTIFICATE OF SERVICE

I hereby certify that on July 15, 2008, a copy of the foregoing was caused to the following by the methods indicated below:

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/s/Marian R. Mackey

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US005904724A

United States Patent [19]

Margolin

[11] **Patent Number:** **5,904,724**

[45] **Date of Patent:** **May 18, 1999**

[54] **METHOD AND APPARATUS FOR REMOTELY PILOTING AN AIRCRAFT**

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

[21] Appl. No.: **08/587,731**

[22] Filed: **Jan. 19, 1996**

[51] **Int. Cl.**[6] **G06F 165/00**; H04N 7/18

[52] **U.S. Cl.** **701/120**; 701/2; 701/24; 244/189; 244/190; 348/114

[58] **Field of Search** 364/423.099, 424.012, 364/424.013, 424.021, 424.022, 449.2, 449.7, 460, 439, 424.028; 340/825.69, 825.72, 967, 989, 991, 992, 993; 244/189, 190, 181, 17.13, 3.11, 3.15; 348/42, 51, 113, 114, 117, 123, 143; 382/154; 395/118, 119, 125

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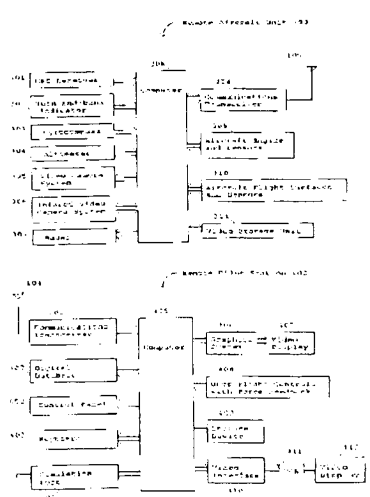
Primary Examiner—Tan Q. Nguyen

Attorney, Agent, or Firm—Blakely, Sokoloff, Taylor and Zafman LLP

[57] **ABSTRACT**

A method and apparatus that allows a remote aircraft to be controlled by a remotely located pilot who is presented with a synthesized three-dimensional projected view representing the environment around the remote aircraft. According to one aspect of the invention, a remote aircraft transmits its three-dimensional position and orientation to a remote pilot station. The remote pilot station applies this information to a digital database containing a three dimensional description of the environment around the remote aircraft to present the remote pilot with a three dimensional projected view of this environment. The remote pilot reacts to this view and interacts with the pilot controls, whose signals are transmitted back to the remote aircraft. In addition, the system compensates for the communications delay between the remote aircraft and the remote pilot station by controlling the sensitivity of the pilot controls.

20 Claims, 7 Drawing Sheets



04938

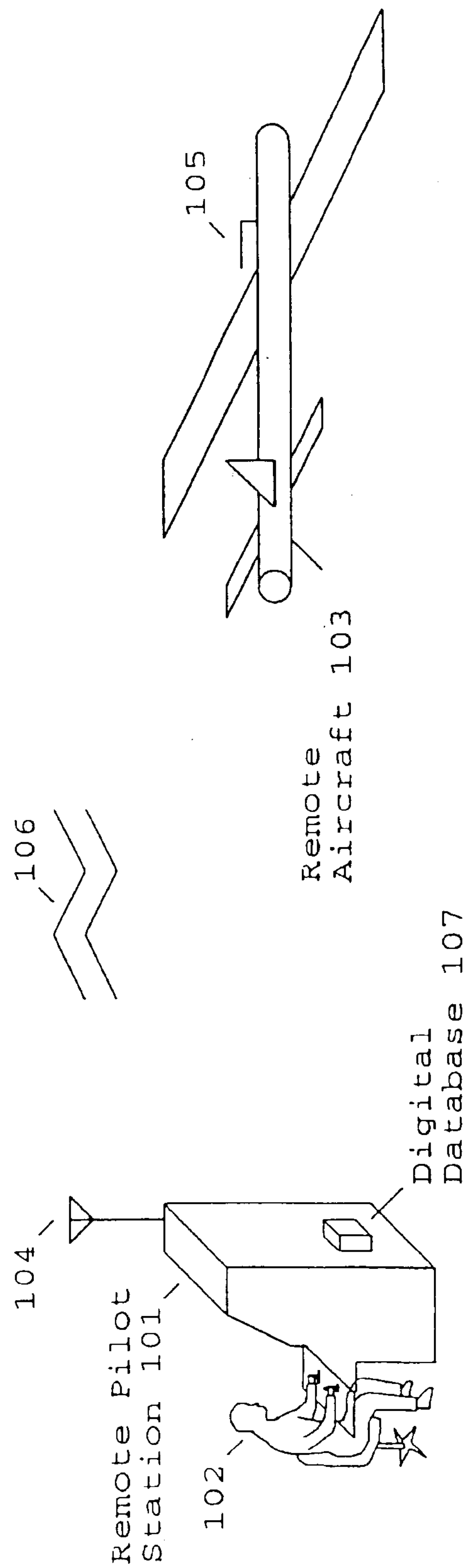

105
Remote Aircraft 103
106
Digital Database 107
104
Remote Pilot Station 101
102

Fig. 1

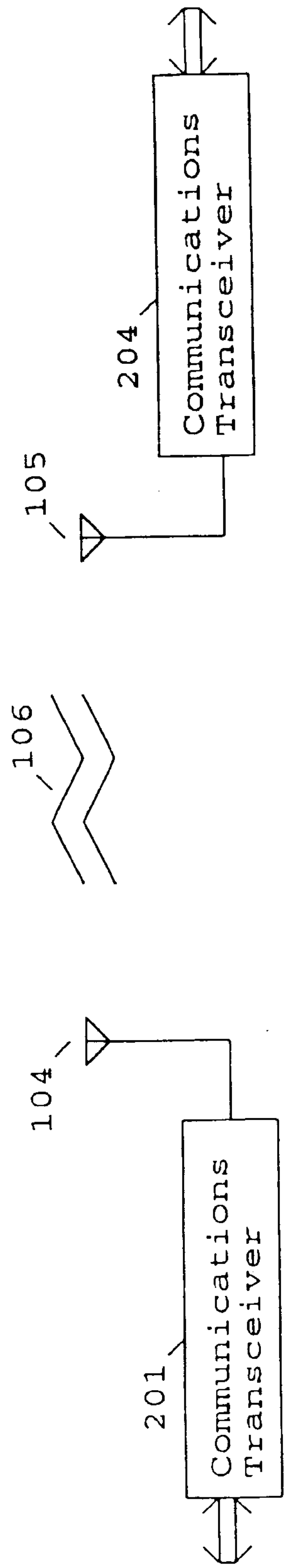

Communications Transceiver
204
105
106
104
Communications Transceiver
201

Fig. 2

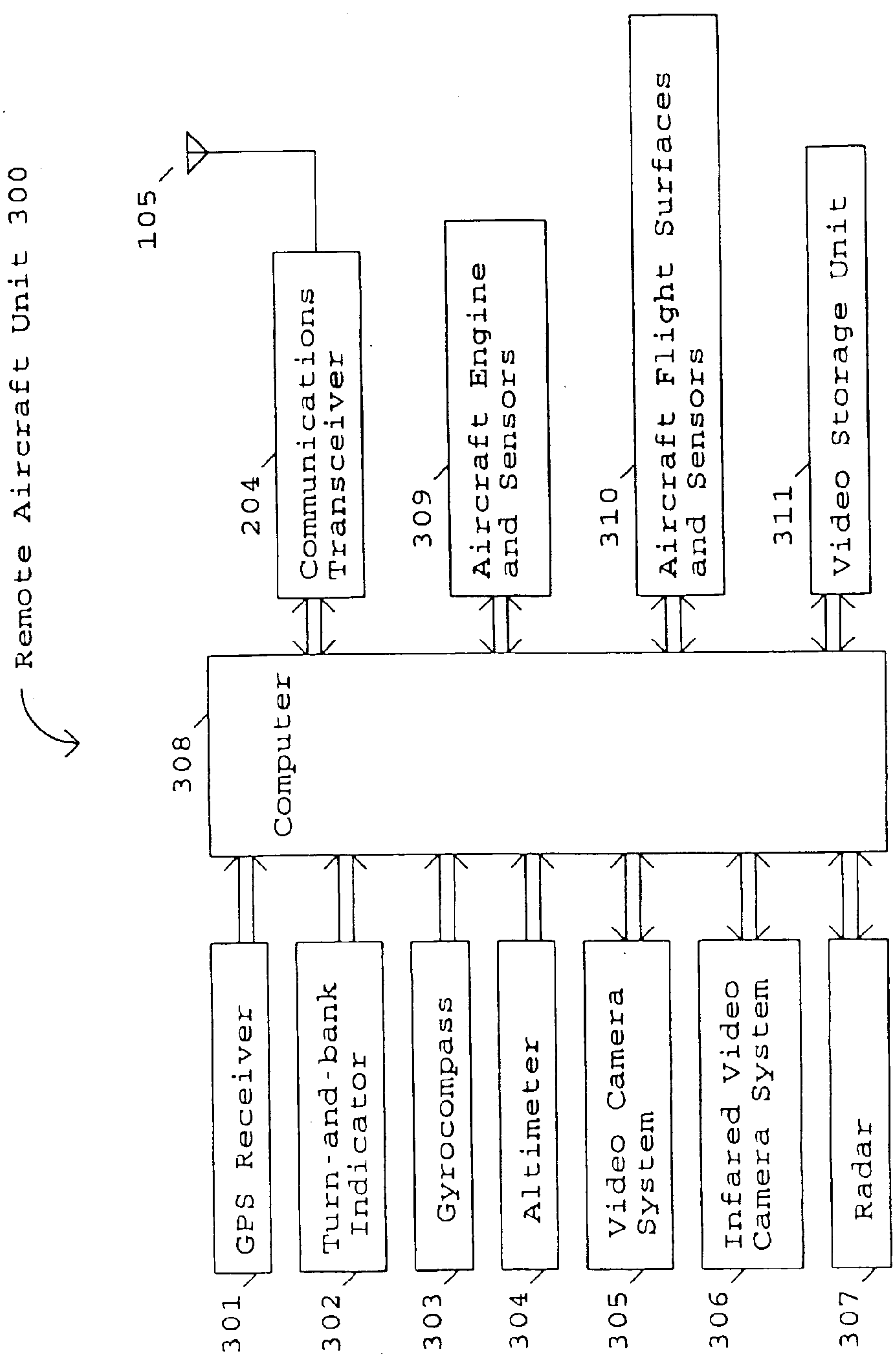

Remote Aircraft Unit 300
105
204
Communications Transceiver
309
Aircraft Engine and Sensors
310
Aircraft Flight Surfaces and Sensors
311
Video Storage Unit
308
Computer
GPS Receiver
Turn-and-bank Indicator
Gyrocompass
Altimeter
Video Camera System
Infared Video Camera System
Radar
301
302
303
304
305
306
307

Fig. 3

4941

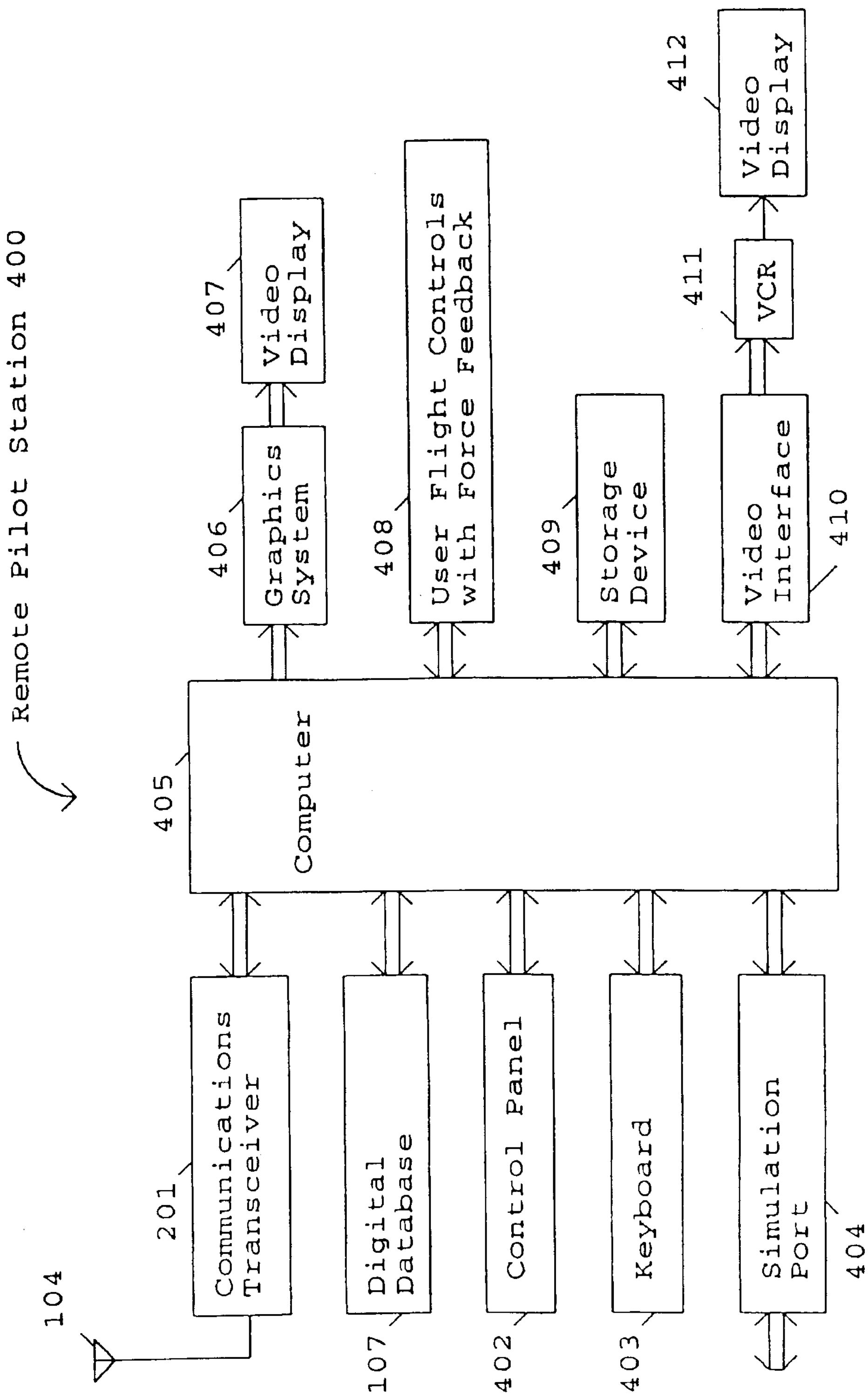

Remote Pilot Station 400
104
201
Communications Transceiver
107
Digital Database
402
Control Panel
403
Keyboard
404
Simulation Port
405
Computer
406
Graphics System
407
Video Display
408
User Flight Controls with Force Feedback
409
Storage Device
410
Video Interface
411
VCR
412
Video Display

Fig. 4

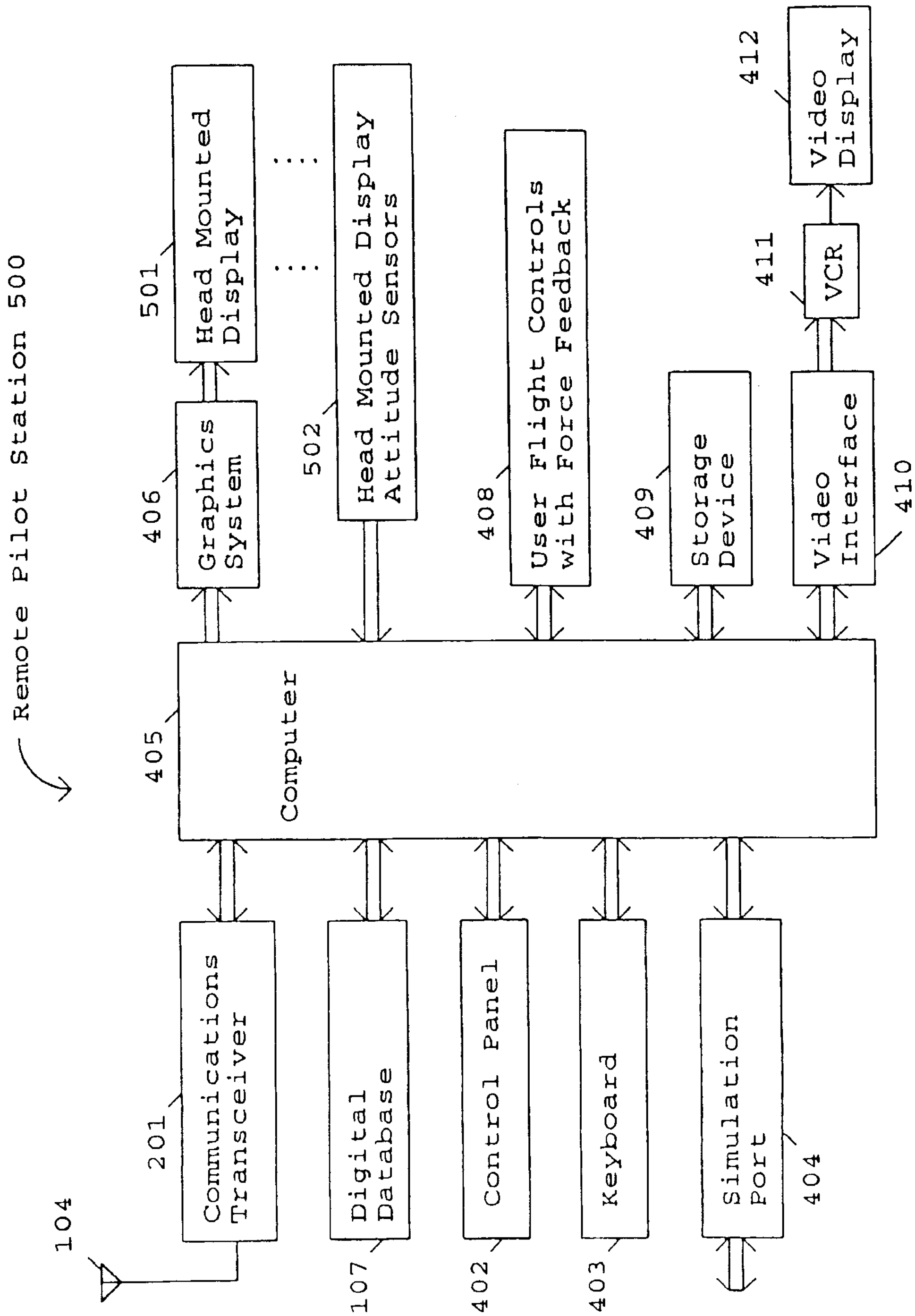

Remote Pilot Station 500
104
201
Communications Transceiver
107
Digital Database
402
Control Panel
403
Keyboard
404
Simulation Port
405
Computer
406
Graphics System
501
Head Mounted Display
502
Head Mounted Display Attitude Sensors
408
User Flight Controls with Force Feedback
409
Storage Device
410
Video Interface
411
VCR
412
Video Display

Fig. 5

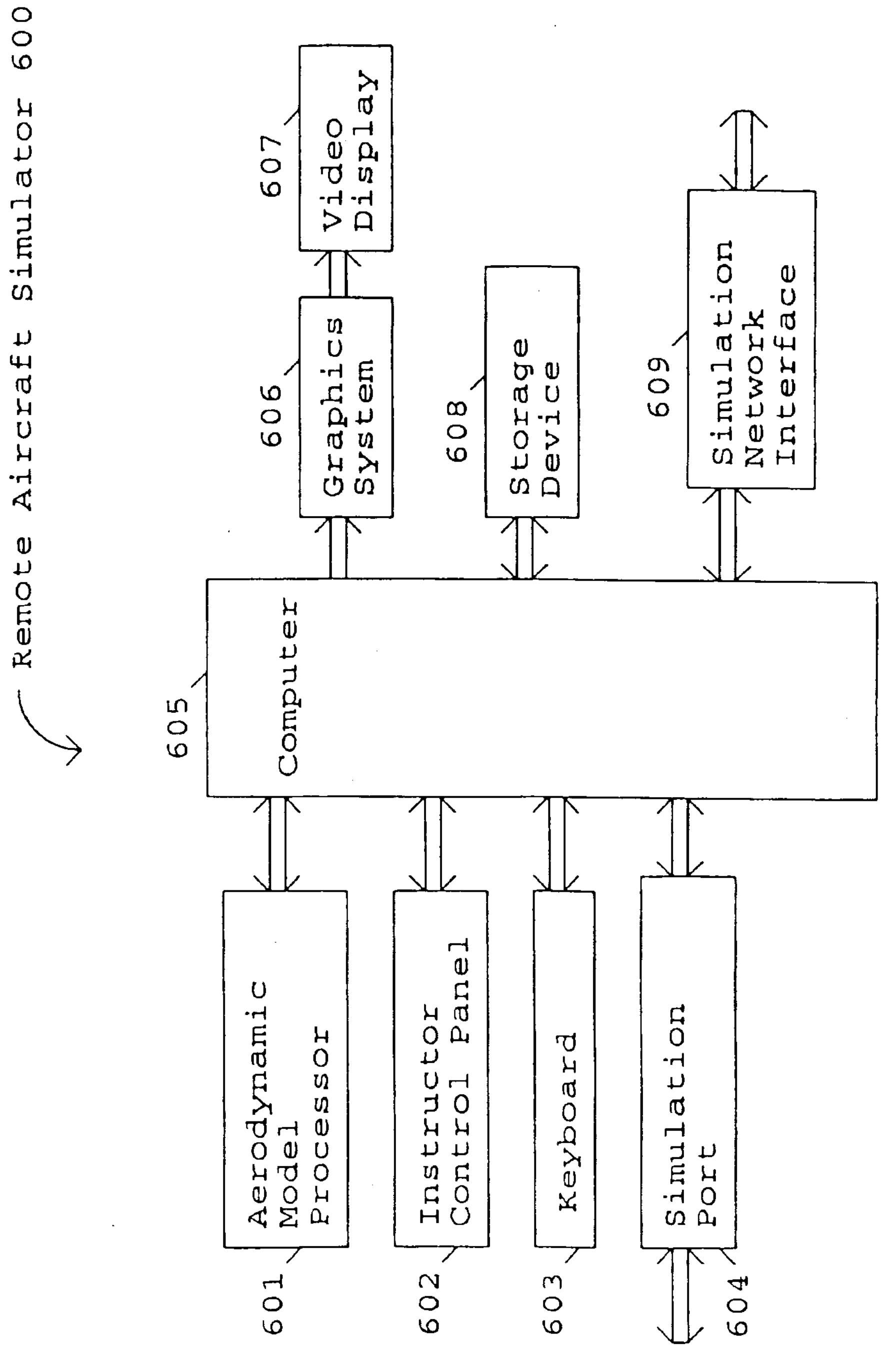

Remote Aircraft Simulator 600
605
Computer
606
Graphics System
607
Video Display
608
Storage Device
609
Simulation Network Interface
601
Aerodynamic Model Processor
602
Instructor Control Panel
603
Keyboard
604
Simulation Port

Fig. 6

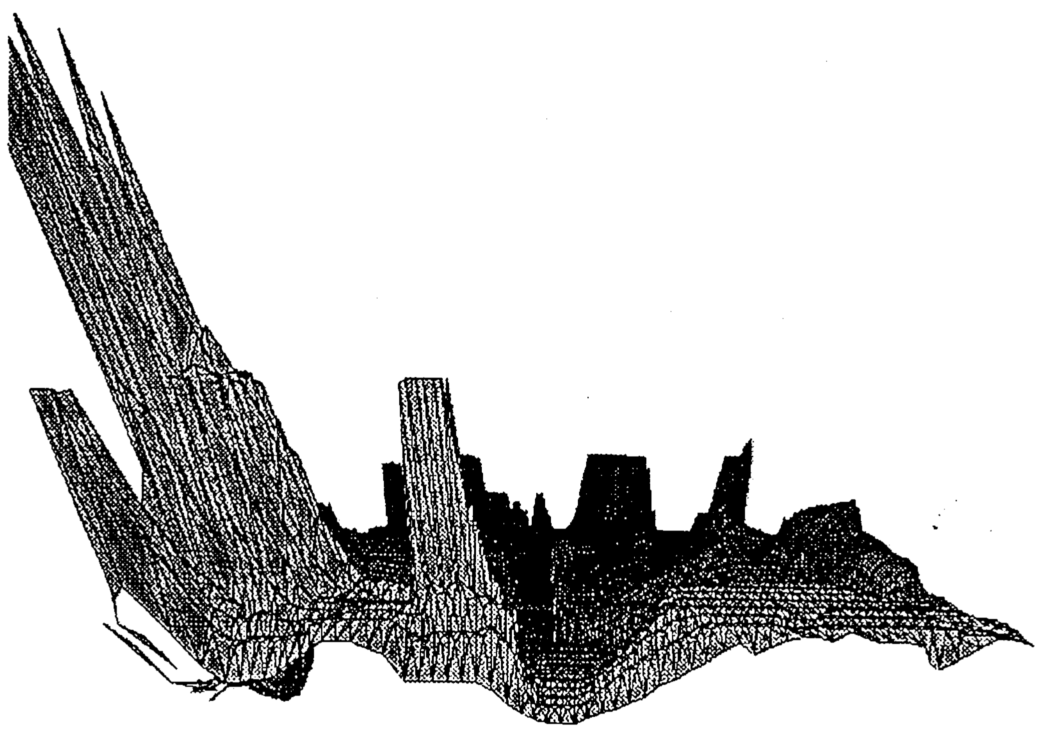


Figure 7

METHOD AND APPARATUS FOR REMOTELY PILOTING AN AIRCRAFT

BACKGROUND OF THE INVENTION—CROSS REFERENCES TO RELATED APPLICATIONS

"Pilot Aid Using a Synthetic Environment", Ser. No. 08/274,394 filed Jul. 11, 1994. "Digital Map Generator and Display System", Ser. No. 08/543,590, filed Oct. 16, 1995.

1. Field of Invention

This invention relates to the field of remotely piloted vehicles (RPVs) and unmanned aerial vehicles (UAVs).

2. Discussion of Prior Art

RPVs can be used for any number of purposes. For example, there is a large organization that promotes the use of remote controlled planes. Certain RPVs are controlled by viewing the plane with the naked eye and using a hand held controller to control its flight Other RPVs are controlled by a remote pilot using simple joysticks while watching the video produced by a camera in the remote aircraft. This camera is also used to produce the reconnaissance video. There are tradeoffs involving the resolution of the video, the rate at which the video is updated, and the bandwidth needed to transmit it. The wider the bandwidth the more difficult it is to secure the signal. The freedom to balance these tradeoffs is limited because this video is also used to pilot the aircraft and must therefore be updated frequently.

Certain UAVs are preprogrammed to follow a predetermined course and lack the flexibility to deal with unexpected situations.

The 1983 patent to Kanaly (U.S. Pat. No. 4,405,943) shows a control and communications system for a remotely piloted vehicle where an oculometer determines where the remote operator is looking and signals the remote vehicle to send the high resolution imagery corresponding to the area around where the remote operator is looking and low resolution imagery corresponding to the remote operator's peripheral vision. The objective is to minimize the bandwidth of the information transmitted to the remote operator.

SUMMARY

A method and apparatus is described that allows a remote aircraft to be controlled by a remotely located pilot who is presented with a synthesized three-dimensional projected view representing the environment around the remote aircraft According to one aspect of the invention, a system is used that includes an aircraft and a remote pilot station.

The aircraft uses a communications link to send its location, attitude, and other operating conditions to the remote pilot station. The remote pilot station receives the data and uses a database describing the terrain and manmade structures in the remote aircraffs environment to produce a 3D view of the remote aircraft environment and present it to the remote human pilot.

The remote pilot responds to the information and manipulates the remote flight controls, whose positions and forces are transmitted to the remote aircraft. Since the amount of data is small, it can be readily secured through encryption and spreadspectrum techniques.

Also, because the video reconnaissance cameras are no longer needed to remotely pilot the aircraft there is great flexibility in their use. To minimize bandwidth and reduce the possibility of being detected, the video data can be sent at a slow update rate. The data can also be stored on the remote aircraft for later transmission. Alternatively, low resolution pictures can be sent in real-time, while the corresponding high resolution pictures can be at a later time. The reconnaissance video can even be transmitted through a different communications link than the control data. There may also be more than one reconnaissance camera.

The delay in the control link must be minimized in order that the remote aircraft can be properly flown. The system can measure the link delay and make this information available to the pilot. This delay link measurement can also be used to modify the control software through which the remote pilot flies the remote aircraft. This is to prevent pilot-induced-oscillation.

The computers in the system allow for several modes of operation. For example, the remote aircraft can be instructed to fly to given coordinates without further input from the remote pilot. It also makes it possible to provide computer assistance to the remote pilot. In this mode, the remote flight control controls absolute pitch and roll angles instead pitch and roll rates which is the normal mode for aircraft In addition, adverse yaw can be automatically corrected so that the resulting control laws make the remote aircraft extremely easy to fly. Because this comes at the expense of being able to put the remote aircraft into unusual attitudes, for complete control of the remote aircraft a standard control mode is provided to give the remote pilot the same type of control that is used to fly a manned aircraft. Since the remote aircraft is unmanned, the remote pilot can subject the remote aircraft to high-G maneuvers that would not be safe for a pilot present in the aircraft.

To facilitate training, a simulated remote aircraft is provided that allows an instructor to set up the training mission and parameters. This is especially useful in giving remote pilots experience flying with different control link delays. In this simulated mode, the system can be further linked to a battlefield simulator such as SIMNET.

In the first embodiment, the remote pilot is provided with a standard video display. Additional display channels can be provided to give the remote pilot a greater field of view. There can even be a display channel to give a rearward facing view.

A second embodiment uses a head mounted display for the remote pilot instead of a standard display. This permits the remote station to be made more compact so that it can be used in a wider variety of installations. An example would be in a manned aircraft flying several hundred miles away.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may best be understood by referring to the following description and accompanying drawings which illustrate the invention. In the drawings:

FIG. 1 is a general illustration showing a remote pilot at a remote pilot station operating a remote aircraft according to one embodiment of the invention.

FIG. 2 is a block diagram showing the communications link between a remote pilot station and a remote aircraft according to one embodiment of the invention.

FIG. 3 is a block diagram of a remote aircraft according to one embodiment of the invention.

FIG. 4 is a block diagram of a remote pilot station according to one embodiment of the invention.

FIG. 5 is a block diagram of a remote pilot station according to another embodiment of the invention.

FIG. 6 is a block diagram of a remote aircraft simulator used for training remote pilots according to one embodiment of the invention.

FIG. 7 is an example of a three dimensional projected image presented to a remote pilot by a remote pilot station according to one embodiment of the invention:

DETAILED DESCRIPTION

In the following description, numerous specific details are set forth to provide a thorough understanding of the invention. However, it is understood that the invention may be practiced without these specific details. In other instances, well-known circuits, structures and techniques have not been shown in detail in order not to obscure the invention.

A method and apparatus is described that allows a remote aircraft to be controlled by a remotely located pilot who is presented with a synthesized three-dimensional projected view representing the environment around the remote aircraft. Since the video from a reconnaissance camera located on the remote aircraft is not used to pilot the remote aircraft, the amount of data transmitted between the remote aircraft and the remote pilot is small. This provides greater flexibility in how the remote aircraft is used and allows the transmitted data to be made more secure. The remote aircraft may be of any type, for example a remote control plane or helicopter as used by recreational enthusiast.

FIG. 1 is a general illustration showing a remote pilot at a remote pilot station operating a remote aircraft according to one embodiment of the invention. FIG. 1 shows Remote Pilot **102** interacting with Remote Pilot Station **101** and controlling Remote Aircraft **103**. Remote Pilot Station **101** and Remote Aircraft **103** respectively include an Antenna **104** and an Antenna **105** for communicating Information **106**.

In one embodiment, Information **106** includes status information concerning the status of Remote Aircraft **103** and flight control information for controlling the flight of Remote Aircraft **103**. The status information is generated by Remote Aircraft **103** and includes the three dimensional position and the orientation (also termed attitude, and comprising heading, roll, pitch) of Remote Aircraft **103**. The status information may also include information concerning the flight surfaces, the engine, an additional altitude reading, etc. Remote Pilot Station **101** uses this status information to retrieve data from a Digital Database **107** which contains a three-dimensional description of terrain and manmade structures over which Remote Aircraft **103** is flying. Based on the three dimensional data retrieved from Digital Database **107**, Remote Pilot Station **101** projects a synthesized three-dimensional projected view of the terrain and manmade structures in the vicinity of Remote Aircraft **103**. Based on this view of the terrain and manmade structures, the Remote Pilot Station **101**, on its own and/or in response to input from Remote Pilot **102**, generates and transmits flight control information to Remote Aircraft **103** which adjusts its flight accordingly.

In one embodiment, the Remote Aircraft **103** is a remote controlled plane or helicopter used for recreational purposes. Since remote controlled planes and helicopters tend to be small in size, the circuitry in such remote aircraft to generate and receive Information **106** is minimized. In such systems, the Remote Pilot Station **101** may be implemented by including additional attachments to an existing portable computer. This allows the user to easily transport the remote aircraft and pilot station to an appropriate location for flight.

FIG. 2 is a block diagram showing a bi-directional communications link between a remote pilot station and a remote aircraft according to one embodiment of the invention. FIG. 2 shows Communications Transceiver **201** coupled to Antenna **104** of Remote Pilot Station **101**, as well as Communications Transceiver **204** coupled to Antenna **105** of Remote Aircraft **103**. In addition, FIG. 2 shows Information **106** being communicated between Antenna **104** and Antenna **105**.

FIG. 3 is a block diagram of a remote aircraft unit used in the remote aircraft according to one embodiment of the invention. FIG. 3 shows Remote Aircraft Unit **300** including Computer **308** coupled to GPS Receiver **301**, Turn-and-bank Indicator **302**, Gyrocompass **303**, Communications Transceiver **204**, Aircraft Engine and Sensors **309**, and Aircraft Flight Surfaces and Sensors **310**. GPS Receiver **301** receives signals from the satellites that make up the global positioning system (GPS) and calculates the aircraft's position in three dimensions. Turn-and-bank Indicator **302** and Gyrocompass **303** provide the aircraft's orientation which comprises heading, roll, and pitch. This data is sent to Computer **308** for transformation into the previously described status information. Computer **308** transmits this status information to Communications Transceiver **204** which produces a radio signal and supplies it to Antenna **105**.

The Aircraft Engine and Sensors **309** are coupled to control the aircraft's engine, while the Aircraft Flight Surfaces and Sensors **310** are coupled to control the aircraft's flight surfaces. The flight control information is received from the remote pilot station by Computer **308** through Antenna **105** and Communications Transceiver **204**. This flight control information is processed by Computer **308** into the necessary signals for transmission to Aircraft Engine and Sensors **309** and Aircraft Flight Surfaces and Sensors **310** to control the aircraft's engine and flight surfaces, respectively. The operation of the aircraft's flight control surfaces will be later described with reference to FIG. 4.

In order to protect against ECM, the communications link between the Remote Pilot Station **101** and the Remote Aircraft **103** may be secured. While any number of different techniques may be used to secure this link, in one embodiment Computer **308** is implemented to encryptldecrypt the data transmitted and Communications Transceiver **204** is implemented to use spread spectrum techniques.

Computer **308** may optionally be coupled to Altimeter **304**, Video Camera System **305**, Infrared Video Camera System **306**, Radar **307**, and/or Video Storage Unit **311**. Altimeter **304** provides an output of the aircraft's altitude as a safety check in the event GPS Receiver **301** malfunctions. Thus, this additional altitude reading may also be transmitted to Remote Pilot Station **101** as part of the status information.

Video Camera System **305** is controlled by Computer **308** which determines where the camera is pointing as well as focusing and the zoom factor. The video produced by the camera is not used by the remote pilot for flying the remote aircraft, so there is more flexibility in using the video. As a result, any number of techniques can be used for receiving the images captured by Video Camera System **305**. As examples:

1. High resolution, high update images may be sent back in real-time through the Communications Link, when the high bandwidth needed can be tolerated.
2. High resolution, low update images may be sent back in real-time through the Communications Link to reduce the bandwidth.
3. The video may be recorded in Video Storage Unit **311** for later transmission.
4. The video may be transmitted through a separate communications link.
5. There may be multiple video cameras.

Infrared Video Camera System **306** is similar to Video Camera System **305** and has the same operating modes.

Radar **307** in Remote Aircraft **103** may be passive or active. It may scan a particular pattern or it may track a selected object. Radar **307** may consist of several Radar units. The information from Radar **307** is processed by Computer **308** so that only the desired information is transmitted over the communication link to the Remote Pilot Station **101** for display.

FIG. **4** is a block diagram of a remote pilot station according to one embodiment of the invention. FIG. **4** shows a Remote Pilot Station **400** including a Computer **405** coupled to Communications Transceiver **201**, Digital Database **107**, Graphics System **406**, User Flight Controls with Force Feedback **408**, and a Storage Device **409**. The Storage Device **409** represents one or more mechanisms for storing data. For example, the Storage Device **409** may include read only memory TROM), random access memory (RAM), magnetic disk storage mediums, optical storage mediums, flash memory devices, and/or other machine-readable mediums. Of course, Digital Database **107** may be stored in one or more machine-readable mediums and/or in Storage Device **409**.

As previously described, Antenna **104** receives the radio signals transmitted by Remote Aircraft **103** representing the status information of Remote Aircraft **103**. These radio signals are transformed by Communications Transceiver **201** and sent to Computer **405**. Communications Transceiver **201** is set to the same mode as Communications Transceiver **204**, so that if, for example, spread spectrum techniques are used, the signal will be transparently received. Computer **405** recovers the data (de-encrypting, if required) so that the data communications from Computer **308** in the Remote Aircraft to Computer **405** in the Remote Pilot Station is transparent. Thus, the bi-directional communications link comprises the combination of Communications Transceiver **201**, Antenna **104**, Antenna **105**, and Communications Transceiver **204**.

As previously described, the status information received by Computer **405** includes the three dimensional position and the orientation of Remote Aircraft **103**. The status information may also include information concerning the flight surfaces, flight sensors, the engine, an additional altitude reading, etc. Computer **405** uses this status information to retrieve data from Digital Database **107** which contains a three-dimensional description of terrain and manmade structures over which Remote Aircraft **103** is flying. The composition and creation of the Digital Database **107** is further described later. Based on the three dimensional data retrieved from Digital Database **107**, Computer **405** performs the mathematical operations to transform and project the three dimensional data to generate video data representing a synthesized three-dimensional projected view of the terrain (and, if desired, manmade structures) in the vicinity or environment of Remote Aircraft **103**. This video data is transmitted to Graphics System **406**, which displays the synthesized three-dimensional projected view on Video Display **407**.

Since the image is generated from the digital database, virtually any image of the environment of the Remote Aircraft **103** can be generated. As examples, the pilot may select the environment to be: 1) a simulated image of what would be seen out of the cockpit of a manned aircraft on a similar flight path; 3) a simulated image of what would be seen when looking in any direction (e.g., backwards, out a side window, etc.); 3) a simulated image of what would be seen if a camera were tailing the remotely piloted aircraft; etc. In addition, the simulated image may be set to any magnification. Thus, the phrase environment of Remote Aircraft **103** is intended to include any image generated with reference to the remote aircraft's position.

The User Flight controls with Force Feedback **408** are used by the remote pilot to input flight path information. The User Flight Controls may be of any number of different types, some of which are further described later herein. The status information received by Computer **405** also includes information received from Aircraft Flight Surfaces and Sensors **310**. This information is used to actuate force feedback circuitry in User Flight Controls With Force Feedback **408**. Remote Pilot **102** observes the synthesized three-dimensional environment displayed on Video Display **407**, feels the forces on User Flight Controls With Force Feedback **408** and moves the controls accordingly. This flight control information is sent through the communications link, to Computer **308**, and is used to control the aircraft flight surfaces in Aircraft Flight Surfaces and Sensors **310**. Remote Pilot **102** also receives data from Aircraft Engine and Sensors **309** through the communications link and is able to send data back to control the engine.

Flight Control

To illustrate the operation of the remote aircraft, a fixed-wing airplane will be described as an example. However, the basic principles apply to other types of aircraft as well. The basic control surfaces of an airplane consist of the ailerons, the horizontal elevators, and the rudder. The ailerons are moved differentially (one up, one down) to rotate the airplane around its roll axis; the horizontal elevators cause the airplane to rotate around its pitch axis; and the rudder causes the airplane to rotate around its yaw axis.

When the ailerons are used to modify the lift characteristics of the wings, one wing creates more lift while the other wing creates less lift. This also changes the drag characteristics of the wings and results in a yaw force that is opposite to the yaw force that results from the tail section causing the airplane to weather-cock into the relative wind. It is this yaw force caused by the airplane weather-cocking into the relative wind that causes a banked airplane to turn. The opposite yaw force produced by using the ailerons is called adverse yaw; the rudder control is used to counteract this force to produce a coordinated turn.

The simplest type of flight control consists of a joystick and a set of rudder pedals. The controls are directly connected to the flight control surfaces. With a joystick, moving the stick left and right moves the ailerons, while moving the stick forward and backward moves the horizontal elevators. The rudder is controlled by two foot pedals, one for each foot, that are mounted on a common shaft and hinged in the middle like a seesaw. Pressing one foot pedal forward causes the other foot pedal to move backward and causes the rudder to also move in one direction. Pressing the other foot pedal causes it to move forward and the opposite pedal to move backward and causes the rudder to move in the opposite direction.

An alternative to the joystick is the control yoke which consists of a wheel attached to a shaft that moves in and out of the control housing. Turning the wheel clockwise or counterclockwise moves the ailerons; moving the wheel shaft in and out moves the horizontal elevators. The rudder pedals as the same as those used with a joystick.

In order to aid in a description of remote aircraft operation, it is thought worthwhile to first describe the operation of non-remotely piloted vehicles. Non-remotely piloted vehicles can be operated in one of two ways (also termed as flight control modes); direct control or computer control (also termed as computer mediated).

Direct Control Non-Remotely Piloted Vehicles

When the flight controls are connected directly to the control surfaces the result is a second order system. Using

the joystick as an example, moving the joystick left or right establishes a roll rate. The airplane continues to roll until the joystick is returned to the center position, after which the airplane remains in the bank angle thus established. The foot pedals are used to counteract the adverse yaw as previously described. Moving the joystick forward or backward establishes a pitch rate. The airplane continues to pitch until the joystick is returned to the center position, after which the airplane remains in the pitch angle thus established. Both the roll rate and the pitch rate are subject to the limits of the airplane's design.

Since the joystick is directly connected to the control surfaces, the aerodynamic forces on the control surfaces are transmitted back to the pilot, giving him or her valuable feedback on how the airplane is flying.

The successful operation of the second order system with the pilot in the loop depends on several factors such as the area and placement of the control surfaces, how much the control surfaces move in response to the movement of the pilot controls, and how long the airplane takes to respond to changes of the control surfaces. The total system characteristics also depend on the reaction time of the pilot. If the resulting system is poorly designed it may be unstable, which means it may not be possible for a human pilot to fly it safely. An example of an unstable system is where the pilot desires to perform a gentle roll to the right and so moves the joystick to the right, the airplane's roll rate is faster than the pilot desires so he/she attempts to compensate by moving the joystick to the left, the airplane rolls left at a rate that is faster than the pilot desires so he/she moves the joystick to the right, and so on, with the pilot constantly overcorrecting and with the aircraft's rolling motions constantly getting larger and larger until the aircraft gets into a condition from which it may not be possible to recover, (e.g., spinning into the ground). The type of loss of control described is usually referred to as 'pilot induced oscillation' and although it may be caused by an inexperienced or inattentive pilot, it is more often caused by poor airplane design. Therefore, new airplane designs are extensively tested to make sure they can be safely flown. Examples of airplanes that use direct control of the control surfaces (Direct Control Second Order Systems) are the Cessna 150 and the Piper Cub.

Computer Mediated Non-Remotely Piloted Vehicles

Computer mediated control systems use a computer between the pilot controls and the control surfaces. The pilot controls are read by the computer, the data are modified in a particular way, and the computer sends control signals to the control surfaces. The computer may also sense the forces on the control surface and use it to control force feedback to the pilot controls. This type of computer mediated control may be used to fly an airplane that would otherwise be unstable, such as the F16 or the F117. Aircraft such as the F16 and F117 are also second order systems because the position of the pilot's joystick represents rate of rotation.

There are risks inherent in a computer mediated system. Although the program can be simulated extensively before using it in an actual airplane, the computer program may be quite large and therefore difficult to simulate under all possible conditions. An example of this is the Swedish JAS 39 Gripen Fighter. Despite extensive simulation of the flight control system, during a test flight a Gripen crashed due to "... the flight control system's high amplification of stick commands combined with the pilot's" large, rapid stick movements"." The pilot had entered a low-speed high-banked turn at a 280 meter altitude with lit afterburners and was leaving the turn when his actions led to 'pilot-induced oscillation'. (Aviation Week & Space Technology, Aug. 23, 1993, pages 72–73).

Having described techniques for operating non-remotely piloted vehicles, the Fight Control Modes for RPVs will be described.

Second Order RPV Flight Control Mode

A second order control system for an RPV is inherently computer mediated because the remote pilot must interact through two computers: the computer in the remote aircraft and the computer in the remote pilot station.

Flying an RPV is further complicated because there are additional time delays in the loop. The computer in the remote aircraft must first determine the aircraft's position and orientation. The additional processing for transmitting a secure signal by encryption and/or spread spectrum techniques may create additional delays. Transmission delay of signals between the remote aircraft and remote pilot station is negligible for a direct path. However, if the signals are relayed through other facilities the delay time may be appreciable, especially if an orbiting satellite is used. There are additional delays in the remote pilot station as the remote aircraft's position and orientation are used to transform the data from the digital database to present the pilot with the synthesized 3D projected view from the remote aircraft. In one embodiment, the RPV system measures the various delays and modifies the control laws used by the computer in the remote pilot aircraft and in the feedback provided by the computer in the remote pilot station to the remote pilot. For example, the computer may adjust the sensitivity of the User Flight Controls **408** according to the delay (e.g., as the delay increases, the computer will decrease the sensitivity of the flight controls). The system also displays the measured delay to the remote pilot.

First Order RPV Flight Control Mode

The stability of the flight control system, and thus the flyability of an RPV, can be improved considerably by using a first order system. In one embodiment of such a first order system the position of the remote pilot's joystick represents an angle relative to the horizon, instead of representing a rate of rotation as in a second order system. The position of the joystick is transmitted to the computer in the remote aircraft which moves the control surfaces as required to place the remote aircraft in the requested orientation. The control system in the remote aircraft is still a second order system but the delays in the communications link and the remote pilot station are no longer a part of the system's loop.

When a joystick is centered, the remote aircraft will fly straight and level. When the joystick is to the right of center the remote aircraft will be in a right banked turn. When the joystick is to the left of center the remote aircraft will be in a left banked turn. When the joystick is backward from center the remote aircraft will be in a pitch up orientation. When the joystick is forward of center the remote aircraft will be in a pitch down orientation.

The amount of bank and pitch permitted depends on the design of the remote aircraft. A high performance remote aircraft will be capable of a greater amount of pitch and bank than will a low performance remote aircraft.

Referring again to FIG. **4**, Computer **405** may optionally be coupled to Control Panel **402**, Keyboard **403**, Simulation Port **404**, Video Interface **410**, VCR **411**, and/or Video Display **412**. In one embodiment, Control Panel **402** contains specialized lights, displays, and switches to allow a quicker response to situations than can be provided by Keyboard **403**. Control Panel **402** can be arranged to approximate the look and feel of an actual aircraft cockpit. Keyboard **403** allows the remote pilot to select various operating modes. For training purposes, Simulation Port **404** allows the remote pilot station to be connected to a remote aircraft simulator instead of an actual remote aircraft. The remote aircraft simulator will be further described with reference to FIG. **6**. Storage Device **409** allows the flight data to be recorded. During playback this previously recorded data is substituted for real-time data from the remote aircraft to replay the mission for analysis. Any video received from any reconnaissance cameras on the Remote Aircraft **103** is converted by Video Interface **410** so that it can be recorded on VCR **411** and displayed on Video Display **412**. VCR **411** can also operate in straight-through mode so that the reconnaissance video can be viewed in real time.

FIG. **5** is a block diagram of a remote pilot station according to another embodiment of the invention. FIG. **5** shows Remote Pilot Station **500**. Remote Pilot Station **500** is similar to Remote Pilot Station **400** of FIG. **4**, except Video Display **407** is replaced by Head Mounted Display **501**. In addition, Head Mounted Display Attitude Sensors **502** are coupled to Computer **405**. Head Mounted Display Attitude Sensors **502** measure the attitude of Head Mounted Display **501**. This information is used by Computer **405** to produce an additional three dimensional transformation of the data from Digital Database **107** to account for the attitude of the remote pilots Head Mounted Display **501**. This does not require any additional data from the remote aircraft. Of course, alternative embodiments could include both a video display and a head mounted display.

FIG. **6** is a block diagram of a simulated remote aircraft used for training remote pilots according to one embodiment of the invention. FIG. **6** shows Remote Aircraft Simulator **600** including Computer **605** coupled to Aerodynamic Model Processor **601**, Instructor Control Panel **602**, Keyboard **603**, Simulation Port **604**, Graphics System **606**, Storage Device **608**, and Simulation Network Interface **609**. Remote Aircraft Simulator **600** communicates with Remote Pilot Station **400** or **500** through Simulation Port **604**. Aerodynamic Model Processor **601** executes a mathematical model that simulates the behavior of a remote aircraft. An instructor uses Instructor Control Panel **602** and Keyboard **603** to select various training scenarios. Graphics System **606** and Video Display **607** are used to observe the operation of the system. Storage Device **608** is used to record the training session for later evaluation of the session. In addition to proficiency training, the Remote Aircraft Simulator can also be used to practice a proposed mission. The data communicated to the remote pilot station can include training and evaluation data for processing and/or display. This training and evaluation data can include any relevant information, such as flight path accuracy, etc.

Simulation Network Interface **609** permits participation in a battlefield simulation system such as SIMNET, mixing aircraft, tanks, and ground troops for training in the coordination of mixed forces. Thus, the system is designed to allow for the communication of this battlefield simulation information between the remote aircraft simulator and the remote pilot station. This allows the remote pilot station to display one or more other simulated entities (e.g., tanks, ground troops, other aircraft, etc.) described by the battlefield simulation information.

The Database

The Digital Database **107** can be comprised of any type of data from which a three dimensional image can be generated. For example, 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.

The other USGS database 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 the remote pilot can select them to be highlighted by category or by specific object.

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

The procedure for generating the synthesized three-dimensional view from the Digital Database may use any number of techniques, including those disclosed in the 1987 patent to Beckwith et al. (U.S. Pat. No. 4,660,157 REAL TIME VIDEO PERSPECTIVE DIGITAL MAP DISPLAY METHOD), and the 1993 patent to Dawson et al. (U.S. Pat. No. 5,179,638 METHOD AND APPARATUS FOR GENERATING A TEXTURE MAPPED PERSPECTIVE VIEW). One disadvantage of generating the synthesized three-dimensional view from these elevation databases in real time is the amount of storage space they require. To avoid this large amount of data storage, one embodiment of Digital Database **107** is composed of terrain data that represents the real terrain using polygons. This database may be generated using any number of techniques. For example, this database may be generated by transforming one or more elevation databases into a polygon database using the technique taught in "Pilot Aid Using a Synthetic Environment", Ser. No. 08/274,394 filed Jul. 11, 1994. Another method for transforming one or more elevation databases into a polygon database is taught in "Digital Map Generator and Display System", Ser. No. 08/543,590, filed Oct. 16, 1995. An example of a three dimensional projected image created from this database is shown in FIG. **7**.

While the invention has been described in terms of several embodiments, those skilled in the art will recognize that the invention is not limited to the embodiments described. The method and apparatus of the invention can be practiced with modification and alteration within the spirit and scope of the appended claims. The description is thus to be regarded as illustrative instead of limiting on the invention.

What is claimed is:

1. A system comprising:
   a remotely piloted aircraft including,
      a position determining system to locate said remotely piloted aircraft's position in three dimensions; and
      an orientation determining system for determining said remotely piloted aircraft's orientation in three dimensional space;
   a communications system for communicating flight data between a computer and said remotely piloted aircraft,

said flight data including said remotely piloted aircraft's position and orientation, said flight data also including flight control information for controlling said remotely piloted aircraft;

a digital database comprising terrain data;

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

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

a set of one or more remote flight controls coupled to said computer for inputting said flight control information, wherein said computer is also for determining a delay time for communicating said flight data between said computer and said remotely piloted aircraft, and wherein said computer adjusts the sensitivity of said set of one or more remote flight controls based on said delay time.

2. The system of claim 1, wherein:

said remotely piloted aircraft includes a device for capturing image data; and

said system operates in at least a first mode in which said image data is not transmitted from said remotely piloted aircraft to said computer at a sufficient data rate to allow for real time piloting of the remotely piloted aircraft.

3. The system of claim 1, wherein the flight data communicated between said remotely piloted aircraft and said computer is secured.

4. The system of claim 1, wherein said remotely piloted aircraft further comprises a set of one or more video cameras.

5. The system of claim 4, wherein said communications system is also for communicating video data representing images captured by said set of one or more video cameras, said video data for displaying said images.

6. The system of claim 5, wherein said video data is transmitted on a different communication link than said flight data.

7. The system of claim 4, wherein at least one camera in said set of one or more video cameras is an infrared camera.

8. The system of claim 1, wherein said display is a head mounted display.

9. The system of claim 1, wherein said set of one or more remote flight controls is responsive to manual manipulations.

10. The system of claim 1, wherein said set of one or more remote flight controls allows for inputting absolute pitch and roll angles instead of pitch and roll rates.

11. The system of claim 1, wherein said computer is also used for correcting adverse yaw without requiring input from said set of one or more remote flight controls.

12. The system of claim 1, wherein:

said remotely piloted aircraft includes a device for capturing image data; and said system operates in at least a first mode in which said image data is not transmitted from said remotely piloted craft to said computer but stored in said remotely piloted aircraft.

13. A station for flying a remotely piloted aircraft that is real or simulated comprising:

a database comprising terrain data;

a set of remote flight controls for inputting flight control information;

a computer having a communications unit configured to receive status information identifying said remotely piloted aircraft's position and orientation in three dimensional space, said computer configured to access said terrain data according to said status information and configured to transform said terrain data to provide three dimensional projected image data representing said remotely piloted aircraft's environment, said computer coupled to said set of remote flight controls and said communications unit for transmitting said flight control information to control said remotely piloted aircraft, said computer also to determine a delay time for communicating said flight control information between said computer and said remotely piloted aircraft, and said computer to adjust the sensitivity of said set of remote flight controls based on said delay time; and

a display configured to display said three dimensional projected image data.

14. The station of claim 13, wherein said communications unit is also configured to receive video data representing images captured by a set of video cameras on said remotely piloted aircraft, said video data for displaying said images.

15. The station of claim 14, wherein said video data is transmitted on a different communication link that said flight control information and said status information.

16. The station of claim 13, wherein said display is a head mounted display.

17. The station of claim 13, wherein said set of remote flight controls is responsive to manual manipulations.

18. The station of claim 13, wherein said set of remote flight controls are configured to allow inputting absolute pitch and roll angles instead of pitch and roll rates.

19. The station of claim 13, wherein said computer is also configured to correct adverse yaw without requiring input from said set of remote flight controls.

20. The station of claim 13, wherein said communications unit includes at least one of a communications transceiver and a simulation port.

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