7-1193-74

HEXAGON

ATTITUDE DETERMINATION IMPROVEMENT ~~(U)~~

25 OCTOBER 1973

(b)(1)
(b)(3)

STUDY OBJECTIVES (U)

- DEFINE NON-PHOTOGRAPHIC ATTITUDE MEASUREMENT AND REPORTING SYSTEMS FOR PROVIDING ACCURATE, LESS THAN 30 SEC ERROR (1σ), POST-FLIGHT DETERMINATION OF SENSOR SUBSYSTEM ATTITUDE DURING STEREO OPERATION.

- FOR EACH SYSTEM DEFINED PROVIDE:
  - DESCRIPTION: EQUIPMENT AND LOCATIONS
  - SV IMPACTS: WEIGHT, POWER, INTERFACES, TEST
  - ESTIMATED PERFORMANCE AND ERROR ANALYSIS
  - PLANNING ROM COSTS AND SCHEDULES
  - DATA PROCESSING AND REPORTING

GROUND RULES AND ASSUMPTIONS (U)

- ERROR IS BETWEEN TCA ALIGNMENT CUBE AND ORBIT PLANE COORDINATES IN ROLL, PITCH AND YAW
- ACCURACY GOAL IS ±10 $\widehat{\text{SEC}}$ 1σ
- SYSTEM IS AUXILIARY TO SV OPERATION – NO FULL REDUNDANCY
- EFFECTIVITY NO LATER THAN SV-19
- MEASUREMENTS NEEDED ON AT LEAST 15% OF TOTAL SS OPERATION WITH ANY OPERATION BEING AT LEAST 10 MINUTES OF STEREO PHOTOGRAPHY
- EQUIPMENT MAY BE LOCATED ON SS HARDWARE

APPROACH (U)

PREVIOUS STUDIES CONCLUSIVELY SHOWED THAT METHODS MOST SUITABLE FOR P-95 APPLICATION AND ACCURACY GOAL ARE STELLAR SYSTEMS. THESE SYSTEMS COMBINE CELESTIAL REFERENCE, STAR SIGHTING INFORMATION, EPHEMERIS DATA, AND VEHICLE MOTION KNOWLEDGE TO PRODUCE AN EARTH REFERENCED ATTITUDE. NECESSARY EQUIPMENT ITEMS FOR THE SYSTEM ARE: A DATA PROCESSOR, A DATA LINK, STAR SENSORS, AND PRECISION RATE GYROS. OPTIONAL EQUIPMENT ITEMS FOR IMPROVED ACCURACY ARE A DOPPLER BEACON SYSTEM AND ON-ORBIT DEFORMATION MEASURING DEVICES.

PROCESSING CONSIDERATIONS (U)

ONBOARD PROCESSING

- REQUIRES ADDITION OF COMPUTER TO SV
- CAN GIVE DIRECT READOUT
- REDUCES DOWNWARD DATA FLOW
- NEEDS EPHEMERIS INPUTS
- PROVIDES ALTERNATE/BACKUP FOR HORIZON SENSORS

GROUND PROCESSING

- RAW DATA REQUIRES HIGH DOWNWARD FLOW
- DATA FLOW DOWNWARD ONLY
- FEWER CONSTRAINTS ON COMPUTATIONAL TECHNIQUES
- MORE ACCURACY
- USES EXISTING GROUND COMPUTER(S)

DATA LINK CONSIDERATIONS (U)

TELEMETRY

- NO ADDITIONAL ASSOCIATE INTERFACE REQUIRED
- FEW PHYSICAL LIMITATIONS ON AMOUNT OR TYPE OF DATA
- UTILIZES EXISTING P-95 TECHNIQUES
- RAW OR PROCESSED DATA EASILY ACCEPTED
- DATA PROCESSED AND ATTITUDES KNOWN WHEN FILM IS AVAILABLE
- USING PRESENT EQUIPMENT WOULD AVOID HIGH EXTRA COSTS

MATERIAL MARKING

- MINIMIZES TELEMETRY INCREASES
- LIMITS ON AMOUNT OF DATA AND TIMING OF DATA
- REQUIRES ADDITIONAL ASSOCIATE INTERFACE
- ATTITUDES NOT AVAILABLE UNTIL AFTER FILM IS RECOVERED AND PROCESSED

OTHER (E.G., RECOVERABLE DATA TAPE)

- NO FURTHER SENSOR SYSTEM IMPACT AND RELATIVELY SIMPLE RV INTERFACE
- ADDITIONAL HARDWARE REQUIRED
- POSSIBLE LIMITATION ON AMOUNT OF DATA
- ATTITUDE OR ATTITUDE DATA NOT AVAILABLE BEFORE RV IS RECOVERED

STAR DETECTOR TYPE TRADE-OFFS (U)

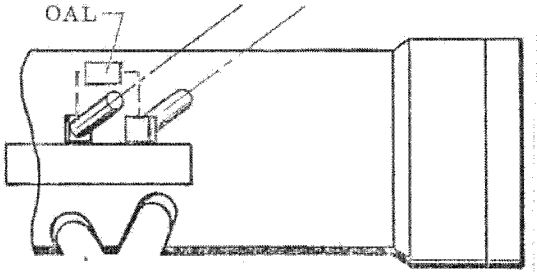
WIDE ANGLE TRACKERS/SCANNERS

- TRACKERS
  - WIDE FIELD OF VIEW: INSTALLATION DIFFICULT
  - MECHANICALLY COMPLEX
  - MODERATE DATA REQUIREMENTS
  - SIMPLE PROCESSING
- SCANNERS
  - WIDE FIELD-OF-VIEW: INSTALLATION DIFFICULT
  - HIGH ACQUIRED/STORED DATA REQUIREMENTS
  - COMPLEX PROCESSING
  - MORE SOPHISTICATED DETECTORS

FIXED SENSORS

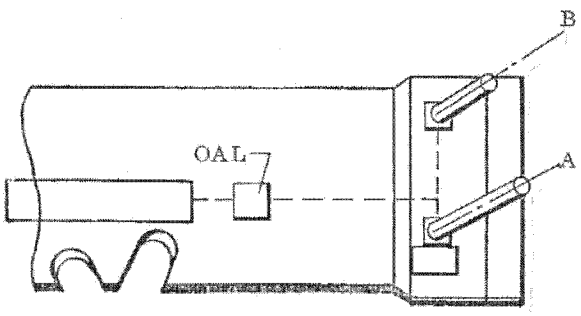
- ACCURATE DISPLACEMENT HISTORY BETWEEN SIGHTINGS NECESSARY
- STAR DATA ACQUISITION AND STORAGE LOW
- MECHANICALLY SIMPLE
- NARROW FIELD-OF-VIEW

SENSOR LOCATIONS



SENSORS ON TCA FRAME

- MINIMAL STRUCTURAL IMPACT
- ADEQUATE SPACE AND FIELD-OF-VIEW
- ASCENT PROTECTION PROVIDED BY PRESENT SHROUD
- CARE REQUIRED TO PRESERVE TCA THERMAL ENVIRONMENT
- MINIMAL STRUCTURAL DEFORMATIONS
- ADDITIONAL ASSOCIATE INTERFACE
- OAL BETWEEN SENSORS TO IMPROVE ACCURACY



SENSORS IN AFT SECTION

A) ON ARM

B) ELSEWHERE

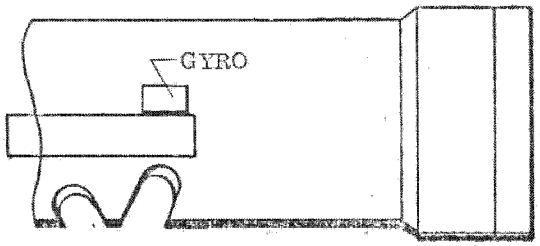
A)

- RCM PRIME STRUCTURAL MODS AND/OR SMALL DIAMETER DETECTORS
- ONLY MINOR ASSOCIATE IMPACT
- REQUIRES ASCENT CONTAMINATION PROTECTION
- OPTICAL ALIGNMENT LINK, OAL, TO TCA REQUIRED FOR DESIRED ACCURACY
- ARM ELEMENTS REPACKAGED BUT ALL SENSORS IN ONE MODULE

B)

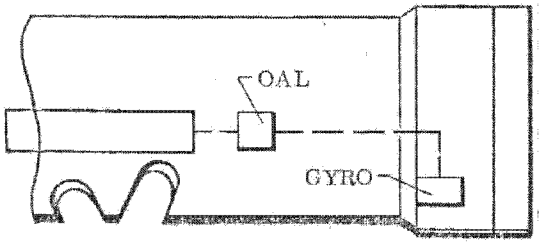
- GOOD FIELD-OF-VIEW
- EQUIP SECTION AND RCM PRIME STRUCTURE MODS
- OAL TO TCA AND ARM GYROs
- REQUIRES ASCENT AERO AND CONTAMINATION PROTECTION

GYRO LOCATIONS



ON TCA FRAME

- MINIMIZES STRUCTURE DEFORMATION EFFECTS
- EFFECTS TCA THERMAL ENVIRONMENT
- ADDITIONAL ASSOCIATE INTERFACE
- IF SUPPLEMENTAL GYRO PACKAGE
  - INCREASED HARDWARE COSTS
  - HIGHER DATA LOAD
- IF RELOCATED (FROM ARM) P-95 IRA
  - CUMBERSOME SV TEST FLOW
  - EXTENSIVE MODULE LEVEL TEST IMPACT



IN AFT SECTION

- PRESENT P-95 GYROs ARE USABLE
  - NO CHANGE OF ARM
  - NO INCREASE IN DATA LOAD
- OAL TO TCA REQUIRED TO MEET ACCURACY GOAL
- MINIMUM, IF ANY, ASSOCIATE IMPACT

GROUND PROCESSING

- MINIMUM CHANGES TO EXISTING SV
- EXTRA FLEXIBILITY IN DEVELOPING SOFTWARE
- LATER ADAPTION TO ON-BOARD PROCESSING IS FEASIBLE

TELEMETERED DATA

- MINIMUM ASSOCIATE IMPACT
- BEST SUITED FOR RAW DATA
- COMPATIBILITY WITH EXISTING SYSTEM

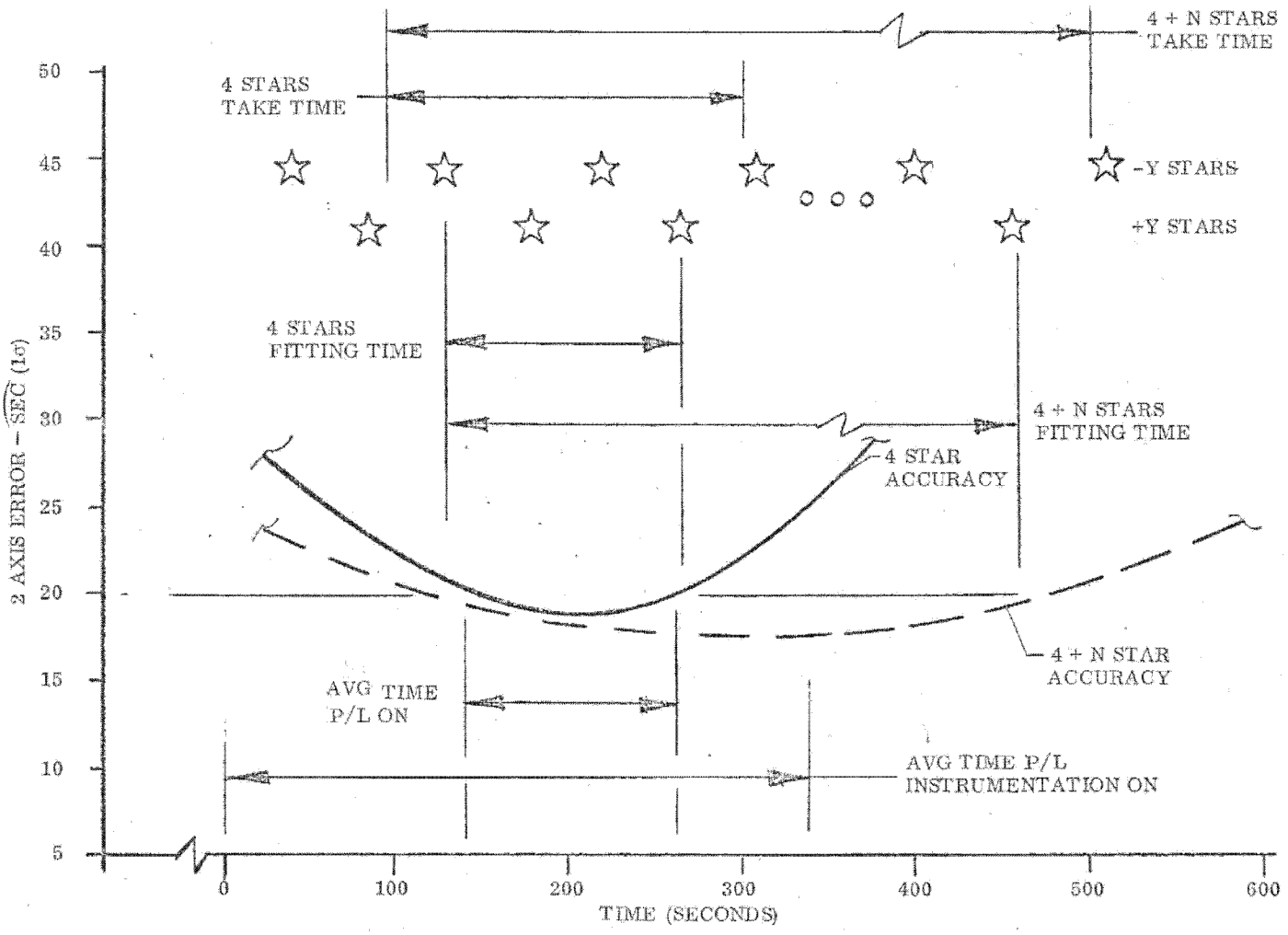
FIXED SENSOR

- LOW STORED/ACQUIRED DATA REQUIREMENTS
- MECHANICAL SIMPLICITY
- SUITABLE HARDWARE DEVELOPED AND/OR QUALIFIED
- RELATIVE EASE OF INSTALLATION

EQUIPMENT INSTALLATION

- SENSORS ON TCA FRAME: MINIMUM STRUCTURAL DEFORMATION AND EASE OF INSTALLATION
- PRESENT IRA, IN ARM, USED: MINIMUM SV IMPACT
- OPTICAL ALIGNMENT LINK, OAL, OPTIONAL TO IMPROVE ACCURACY

SYSTEM OPERATION



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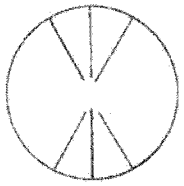
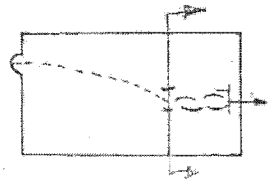
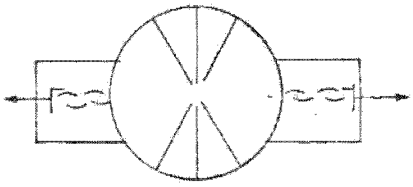
STAR SENSORS (2 PER VEHICLE)

	SOLID STATE SENSOR	IMAGE DISSECTOR	PHOTO MULTIPLIER
			
Detector	6 Silicon Detectors	1 Image Dissector	2 Photo Multipliers
Qualification Status	Just Now Completing Flight Qual.	Qualified	High Likelihood of Qual.
Accuracy (1σ)	Random 6 sec Systematic 6 sec	Random 10 sec Systematic 7 sec	Random 4 sec Systematic 4 sec
Field of view	10°	8° Square	6°
Aperture Dia.	2.75 in.	3.4 in.	
Star Magnitude	3.8	6	5.5
Telescope	3.8" Dia. x 7.8 long		6" Dia. x 10" long
Overall	4.8 " Dia. Flange	12" X 6" X 5.25"	10" Dia X 10" Long
Weight	6.6 pounds	18 pounds	30 pounds
Power	2 watts	10 watts	15 watts
Sun Shield Dimensions (est.)	Max. 8.6 in dia. 14 in. long	Max. 12 in dia. 15 long	Max. 11 in dia. 22 long
Cost	135K	75K	250K
Data Requirements	8ms accuracy time word + slit identification	13 bit digital word each axis	8 ms accuracy time word

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EQUIPMENT — OPTICAL ALIGNMENT LINK

COST ESTIMATES

Supplier	Configuration/ Random Accuracy	Qual. Cost	Recurring (6 Units)	Total (6 Units)
Barnes	2 axis/3 $\widehat{\text{sec}}$	$ 120K	$ 280K	$ 400K
	Twist axis/5 $\widehat{\text{sec}}$	$ 180K	$ 400K	$ 580K
Perkin Elmer	2 axis/3 $\widehat{\text{sec}}$	?		$ 800K
	3 axis/3 $\widehat{\text{sec}}$	?		$ 1.2 M
ITT (image dissector)	2 axis/3 $\widehat{\text{sec}}$	$ 120K*	$ 500K	$ 620K

*Estimated no contact

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YAW ERRORS

(Sec 1σ)

ERROR SOURCE	T = 370 SEC SOLID STATE			T = 35 SEC IMAGE DISSECTOR			T = 90 SEC PHOTO MULTIPLIER		
	A**	B	C	A	B	C	A	B	C
Star Sensor Random	12	12	12	10	10	10	8	8	8
Star Sensor Systematic	6	6	6	7	7	7	5	5	5
OAL Random	---	3	3	---	3	3	---	3	3
OAL Systematic	---	---	3.5	---	---	3.5	---	---	3.5
*Attitude Solution Error (2 axis)	9	9.1	9.1	8.7	8.8	9.5	6.58	6.75	7.6
Structural Fit — Vehicle + Frame	13	—	—	.5	—	—	2	—	—
Structural Fit — Frame Only	—	3	—	—	—	—	—	1	—
Undetectable Frame Shift	15	15	—	15	15	—	15	15	—
OAL Random	—	3	3 —	—	3	3	—	3	3
Ephemeris	2	2	2	2	2	2	2	2	2
Total RSS	22	18	10	17	17	10	17	17	9

$$*\text{Attitude Solution Error} = \left\{\frac{1}{4}\left(E^2_{Random} + QT\right) + E^2_{Sys}\right\}^{1/2}$$

$$Q = .1\ \frac{(°/hr)^2}{Hz}$$

**A — No OAL
B — OAL TCA to Gyros
C — OAL'S SENSOR TO SENSOR AND TCA TO GYROS

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NADIR POINTING ERRORS

ERROR SOURCE	T = 370 SEC SOLID STATE			T = 35 SEC IMAGE DISSECTOR			T = 90 SEC PHOTO MULTIPLIER		
	A**	B	C	A	B	C	A	B	C
Star Sensor Random	6	6	6	10	10	10	4	4	4
Star Sensor Systematic (to reference cube)	6	6	6	7	7	7	5	5	5
OAL Random		3	3.7		3	3.7		3	3.7
OAL Systematic	---	---	5	---	---	5	---	---	5
*Attitude Solution Error (2 axis)	13.5	14.5	14.5	18.9	19.2	21	10	11	13.5
Structural Fit: Vehicle + Frame	24	—	—	1	—	—	4	—	—
Structural Fit: Frame Only	—	6	—	—	:25	—	—	1	—
Undetectable Frame Shift	30	30	—	30	30	—	30	30	—
OAL Random		4.2	4.2		4.2			4.2	4.2
Ephemeris	4	4	4	4	4	4	4	4	4
Total RSS	41	35.	17	36	36	22	32	33	15

*Attitude Solution Error = $(2.6 \times E^2_{Random} + 2 E^2_{Sys} + 0.4\ QT)^{1/2}$

$$Q = .1 \frac{(°/hr)^2}{Hz} \text{ (Gyro Noise Power)}$$

**A — No OAL
B — OAL TCA to Gyros
C — OAL'S Sensor to Sensor and TCA to Gyros

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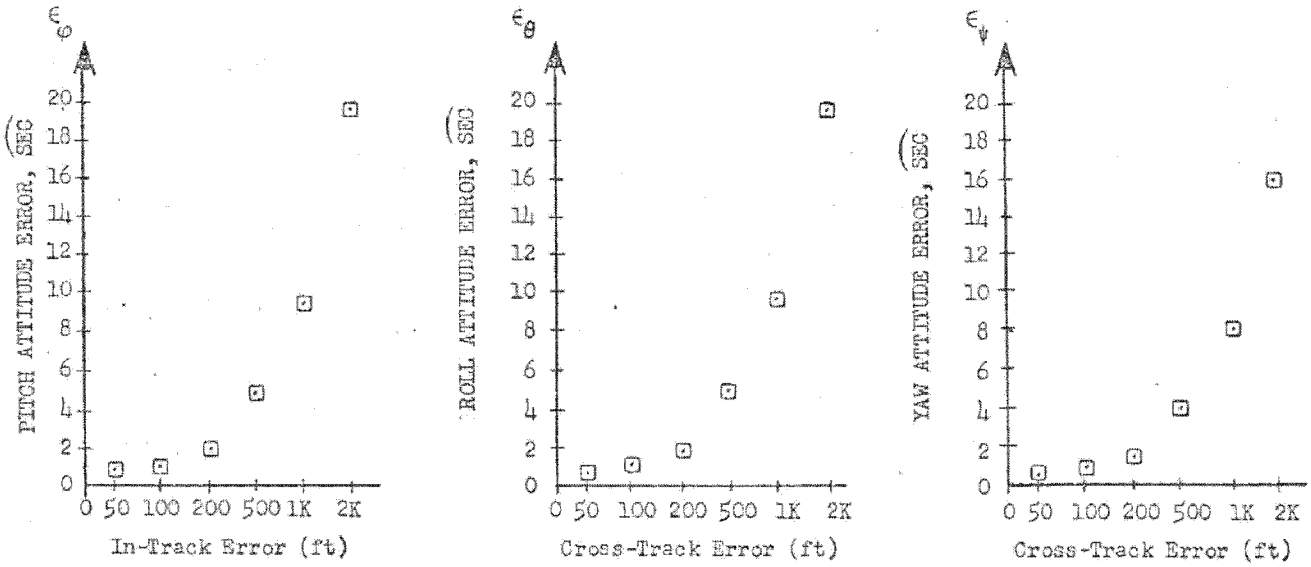
EFFECT OF EPHEMERIS ERRORS ON ATTITUDE ERRORS

- cross-track error maps into roll error
- cross-track error maps into yaw error*
- in-track error maps into pitch error
- radial error has no first order effect

*via cross-track velocity error

Ephemeris Errors



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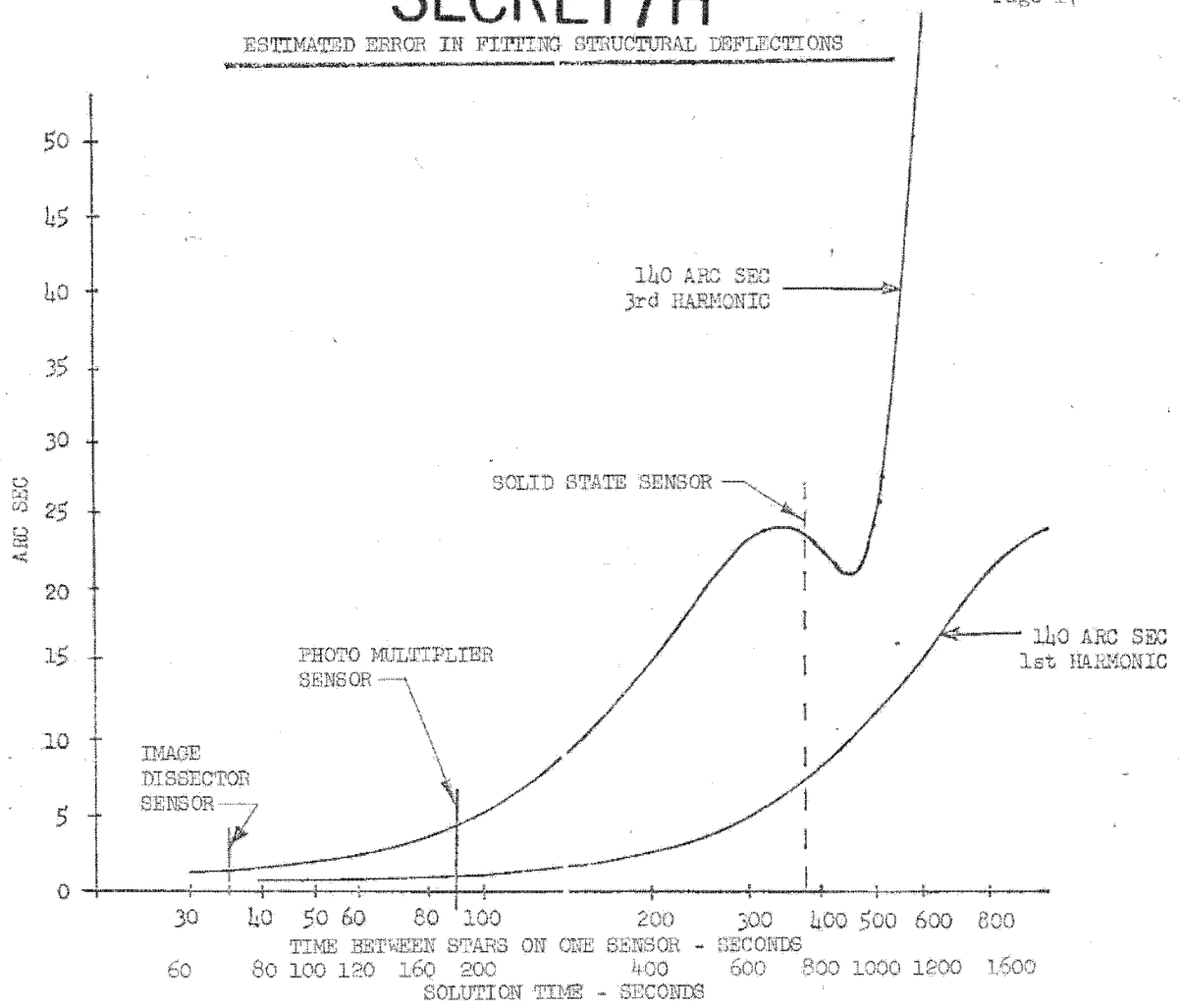
ESTIMATED ERROR IN FITTING STRUCTURAL DEFLECTIONS



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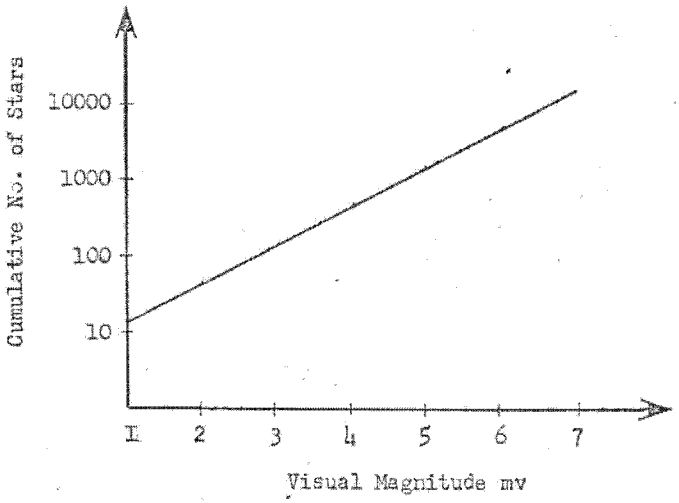
STAR AVAILABILITY VS. SENSITIVITY



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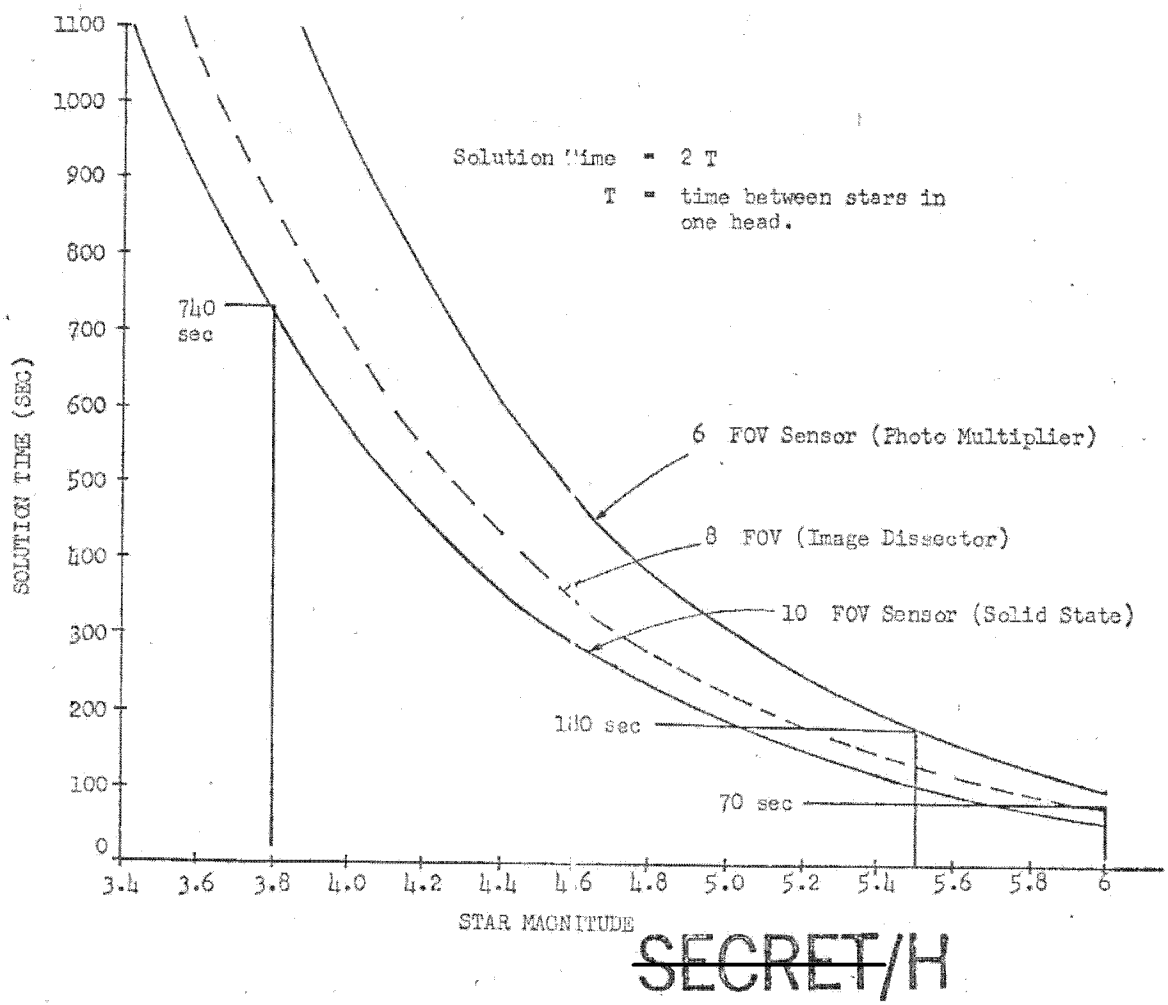
ATTITUDE SOLUTION TIME VS STAR MAGNITUDE



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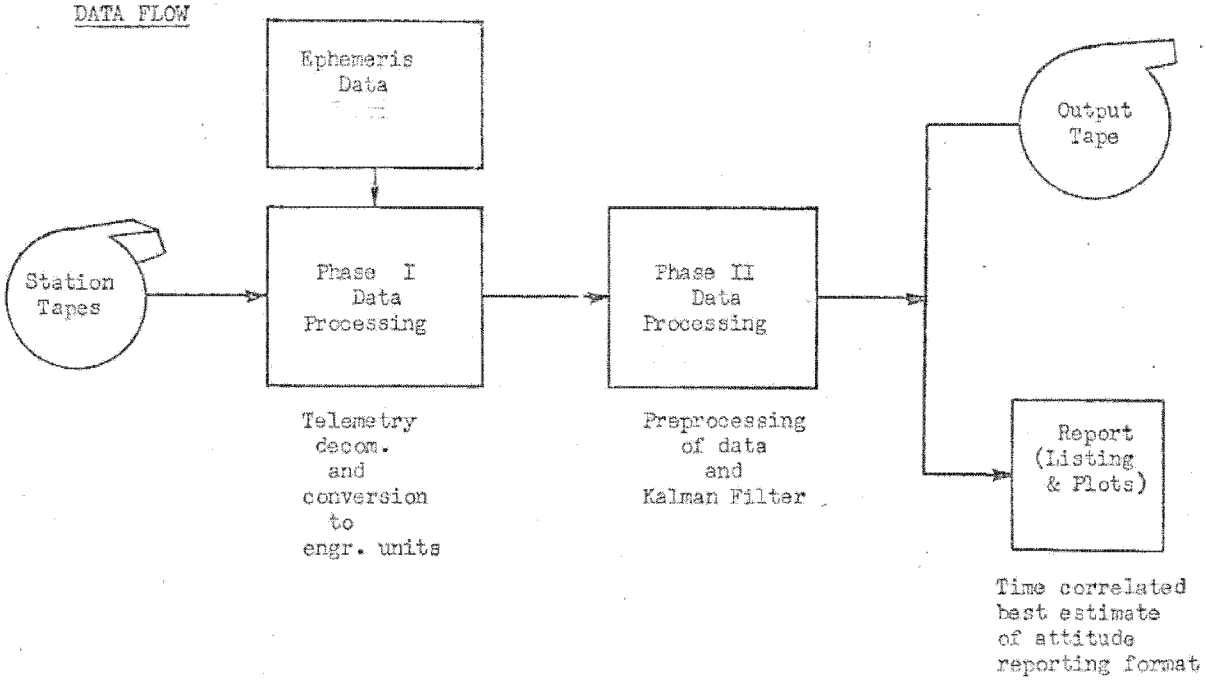
GROUND DATA PROCESSING

DATA FLOW



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THE RECOMMENDED SYSTEMS ARE A SERIES OF SYSTEMS IMBODYING THE SELECTED APPROACH FEATURES AND COVERING A RANGE OF PERFORMANCE AND COSTS. AT ONE END OF THE SERIES IS A SYSTEM WHICH ADDS ONLY IMAGE DISSECTOR SENSORS TO THE TCA FRAME FOR AN OVERALL ATTITUDE OF TCA REFERENCE CUBE ACCURACY OF APPROXIMATELY 30 $\widehat{\text{SEC}}$. AT THE OTHER END IS A SYSTEM USING PHOTOMULTIPLIER SENSORS AND OPTICAL ALIGNMENT LINKS BETWEEN THE SENSORS AND ARM GYROS WHICH MEETS THE ACCURACY GOAL OF 10 $\widehat{\text{SEC}}$. THE ADDITIONAL OPTICAL LINKS OF THE LATTER SCHEME SUGGEST REMOTE MOUNTING OF THE DETECTORS SINCE DEFORMATION IS NO LONGER A CONCERN, THEREBY REDUCING ASSOCIATE INTERFACE IMPACT AND FACILITATING INSTALLATION. SCHEMES USING SOLID STATE DETECTORS ARE NOT RECOMMENDED BECAUSE OF THEIR LONG SOLUTION TIME.

SENSOR	PARAMETER	SGLS TRACKING			DOPPLER TRACKING
		NO OAL	OAL ARM/TCA	OALS ARM/SENSOR	OALS ARM/SENSOR
IMAGE DISSECTOR 70 SECONDS SOLUTION TIME	ACCURACY, $\widehat{SEC}$ 1σ 2 AXIS NADIR/YAW	36/17	36/17	23/11	22/10
	Δ WEIGHT POUNDS	120	166	211	231
	Δ POWER WATTS	25	50	75	80
	COST*, $1,000 TOTAL/NONRECURRING	5,240/1,980	7,243/2,003	8,585/2,945	8,837/3,125
PHOTO MULTIPLIER 180 SECONDS SOLUTION TIME	ACCURACY, $\widehat{SEC}$ 1σ 2 AXIS NADIR/YAW	32/17	33/17	16/10	15/9
	Δ WEIGHT POUNDS	137	182	228	248
	Δ POWER WATTS	30	55	80	85
	COST*, $1,000 TOTAL/NONRECURRING	6,770/1,562	9,068/2,360	10,130/2,522	10,382/2,702

THE IMPACT OF ADDING ANY OF THE RECOMMENDED SYSTEMS TO THE SV IS SMALL. BY THE USE OF THE APPROPRIATE SIGNAL CONDITIONING DESCRIBED, THE EXISTING TELEMETRY SYSTEM CAN HANDLE THE ADDITIONAL DATA. COMMAND AND POWER INCREASES ARE SMALL AND CAN READILY BE ACCOMMODATED. STRUCTURAL CHANGES ARE EASILY MANAGED SINCE ADDED EQUIPMENT IS LIGHT WEIGHT AND LOCATIONS HAVE BEEN SELECTED TO AVOID REDESIGN OF PRIME STRUCTURE. EXTENSIVE ANALYSIS WILL BE REQUIRED TO INSURE THAT AN ACCEPTABLE SENSOR SUBSYSTEM THERMAL ENVIRONMENT IS RETAINED. ALTHOUGH IT APPEARS TO BE NO PROBLEM FOR EXISTING TECHNIQUES, AND TO ACCURATELY PREDICT STRUCTURAL MOTION AND STABILITY AFFECTING SYSTEM ACCURACY, SOME UNCERTAINTY EXISTS IN THE AREA OF SYSTEM CALIBRATION, WHICH CAN ONLY BE RESOLVED BY BETTER DEFINITION OF THE SYSTEM TO BE USED, MORE KNOWLEDGE OF THE EXISTING IN-FLIGHT ENGINEERING TEST CAPABILITIES, AND DESIRED LEVEL OF PERFORMANCE. DEVELOPMENT OF ATTITUDE SOLUTION ALGORITHMS AND IMPLEMENTING SOFTWARE IS BASICALLY THE SAME AS THAT DONE FOR THE QUANTIC EXPERIMENT; HOWEVER, PARTICULAR ATTENTION WILL HAVE TO BE GIVEN TO HANDLING AND REPORTING METHODS WHICH WILL ASSURE TIMELY DELIVERY OF THE ATTITUDE INFORMATION TO THE INTERESTED USER.

- PHOTO MULTIPLIER (2)

SIGNALS	HARDWARE REQUIREMENT	REMARKS
1 DISCRETE EVENT/SS 1 MAGNITUDE ANALOG/SS REPETITION RATE – 10 SEC	• MODIFY DIU TO ACCEPT (1) DISCRETES/SS AND RESOLVE TO ±1 MILLISEC. UPDATE EVERY 100 MILLISEC. OUTPUTS TO PCM 8 DISCRETES SAMPLED AT 20 SPS. • (1) ANALOG/SS DIRECT TO PCM SAMPLED AT 20 SPS • RECORD DATA FOR A MINIMUM OF 10 MINUTES AND UP TO 20 MINUTES/REV MAX • 8 REDUNDANT ON/OFF COMMANDS	ADDS 8-BIT DATA COUNTER FOR SS 1 AND 2 ADDS (2) 8-BIT STORAGE REGISTERS AND DRIVERS ADDS ONE ANALOG/DISCRETE SLICE TO PCM SYSTEM PRESENT SYSTEM CAN BE USED FOR DATA STORAGE, READOUT AND COMMANDING

STAR SENSOR (SS) DATA PROCESSING (CONT.)

- SOLID STATE (2)

SIGNALS	HARDWARE REQUIREMENT	REMARKS
6 DISCRETE EVENTS/SS 6 MAGNITUDE ANALOGS/SS REPETITION RATE – 10/SEC	• MODIFY DIU TO ACCEPT (6) DISCRETES/SS; IDENTIFY ONE OF SIX AND RESOLVE TIME OF OCCURRENCE TO 8 MILLISEC. UPDATE EVERY 1.0 SEC. OUTPUTS TO PCM 8 DISCRETES SAMPLED AT 10 SPS. • MODIFY DIU TO ACCEPT (6) ANALOGS/SS MULTIPLEX TO A SINGLE OUTPUT TO PCM AT 10 SPS • RECORD DATA FOR 10 MINUTES MINIMUM, AND UP TO 20 MINUTES/REV MAX. • 8 REDUNDANT ON/OFF COMMANDS	ADDS INPUT AND DECODE CIRCUITRY, 8-BIT DATA WORDS FOR SS 1 AND 2 ADDS INPUT AND MULTIPLEX CIRCUITRY, SINGLE ANALOG OUTPUT BUFFER ADDS ONE ANALOG/DISCRETE SLICE TO PCM SYSTEM PRESENT SYSTEM CAN BE USED FOR DATA STORAGE READOUT, AND COMMANDING

STAR SENSOR (SS) DATA PROCESSING (CONT.)

- IMAGE DISSECTOR (2)

SIGNALS	HARDWARE REQUIREMENT	REMARKS
1 - X POSITION ANALOG 1 - Y POSITION ANALOG 1 - MAGNITUDE ANALOG REPETITION RATE - CONTINUOUS	• NEW DEVELOPMENT OF DUAL CHANNEL STAR SENSOR CONVERTER. RESOLVE X AND Y POSITION TO 3.5 SECONDS OF 8 DEGREES FULL SCALE (13 BITS). UPDATE EVERY 0.2 SECONDS OUTPUT TO PCM 28 DISCRETES SAMPLED AT 5 SPS. • (1) MAGNITUDE ANALOG DIRECT TO PCM SAMPLED AT 5 SPS. • MODIFY DIU FOR (2) 5 PPS OUTPUTS TO DUAL SS CONVERTER. • RECORD DATA FOR 10 MINUTES MINIMUM AND UP TO 20 MINUTES/REV MAX • 8 ON/OFF COMMANDS	STAR SENSOR CONVERTER WILL CONTAIN: 2 - POWER SUPPLIES 4 - ISOLATED INPUTS 4 - SAMPLE AND HOLD AMPS 4 - A TO D CONVERTERS (14-BIT) 2 - OSCILLATORS AND CONTROL TIMING 4 - 14-BIT PARALLEL OUTPUTS ADD (2) OUTPUT BUFFERS TO DIU ADDS ONE ANALOG/DISCRETE SLICE TO PCM SYSTEM PRESENT SYSTEM CAN BE USED FOR DATA STORAGE, READOUT AND COMMANDING

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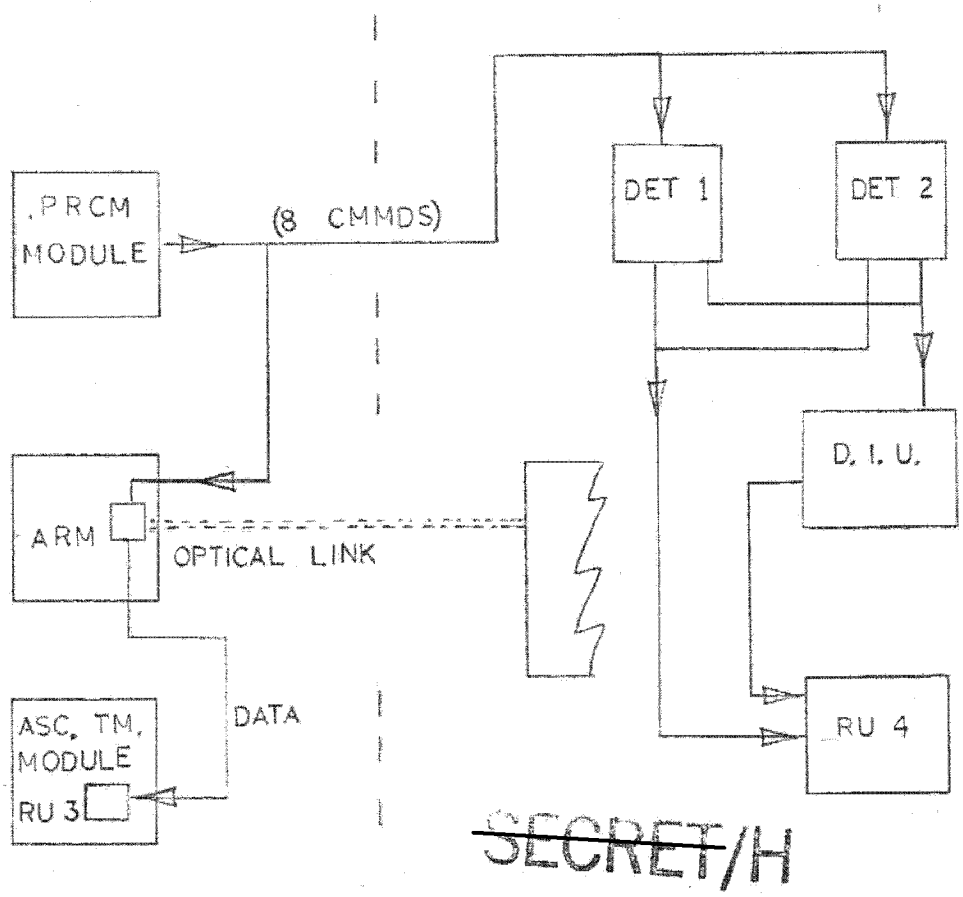
BLOCK DIAGRAM – PHOTOMULTIPLIER AND SOLID STATE (U)



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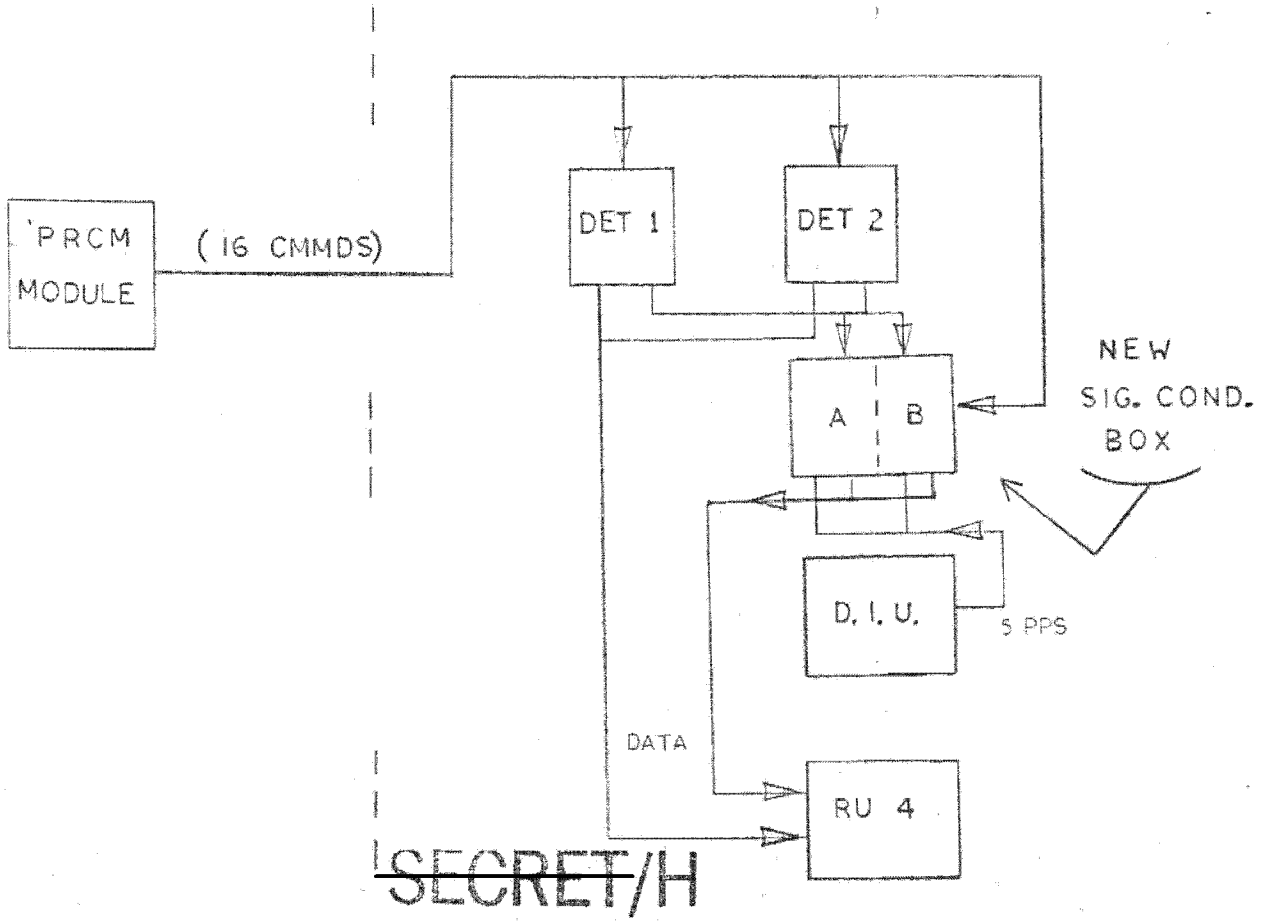
BLOCK DIAGRAM – IMAGE DISSECTOR (U)



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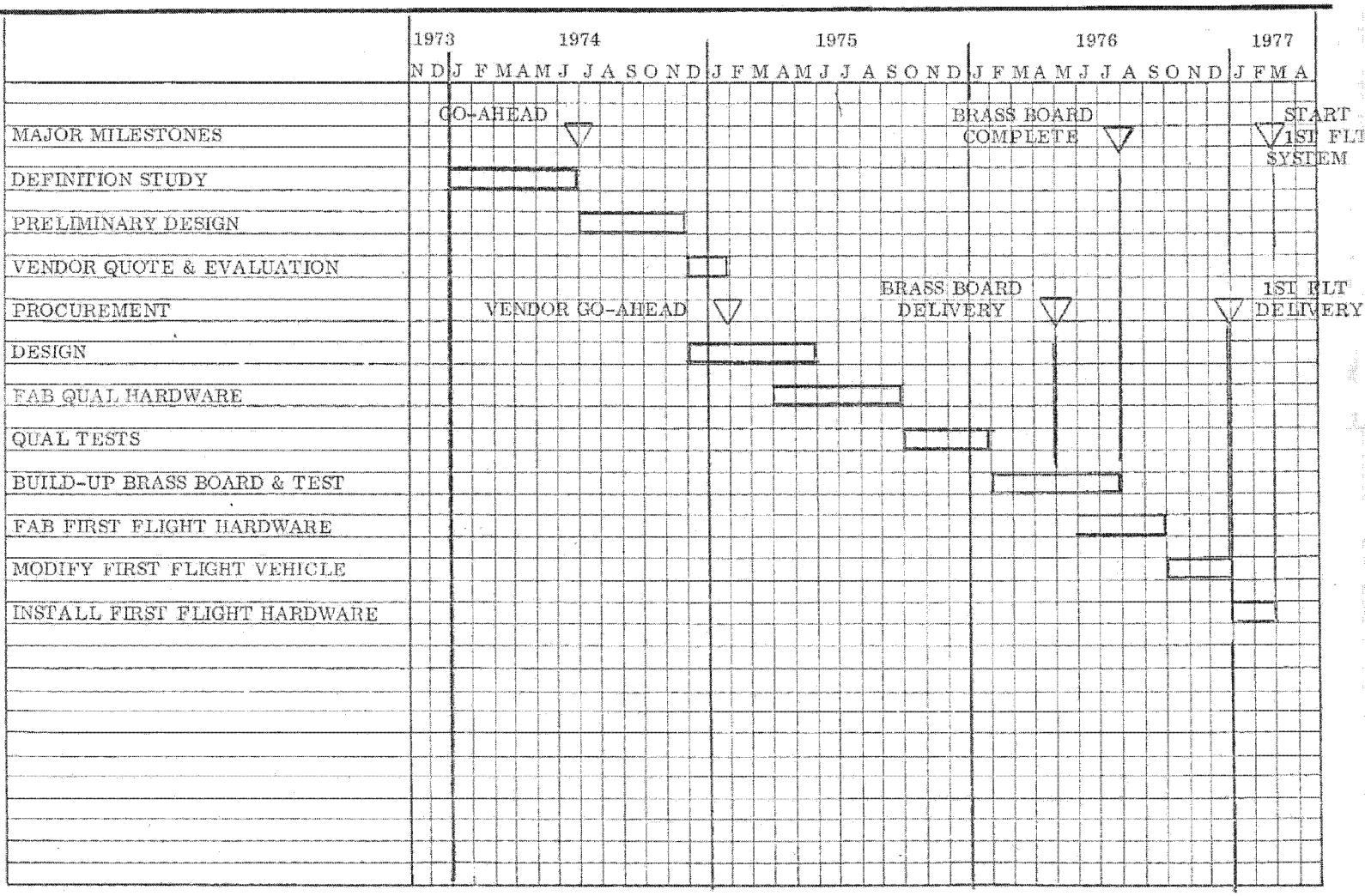
TYPICAL SCHEDULE (U)



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CONCLUSIONS (U)

THERE EXISTS FEASIBLE CONCEPTS TO ACHIEVE ACCURACIES AS LOW AS 10 SEC (1σ) AT THE TCA ALIGNMENT CUBE. SUITABLE SENSORS SHOULD BE AVAILABLE AND CAN BE ACCOMMODATED WITH LITTLE SV HARDWARE IMPACT. THE MAJOR OPEN PROBLEM AREAS OF THESE CONCEPTS ARE:

- STRUCTURAL DEFORMATION MODELING AND FITTING
- DEFINITION OF GROUND TEST PROGRAM
  - VERIFICATION OF ALIGNMENT STABILITY
  - BRASS BOARD PERFORMANCE VERIFICATION
  - VEHICLE ACCEPTANCE TEST REQUIREMENTS
- DEFINITION OF FLIGHT TEST PROGRAM
  - VERIFICATION OF ALIGNMENT STABILITY USING APSA
  - DETERMINATION OF ON-ORBIT CALIBRATION CAPABILITY WITHOUT APSA
- VERIFICATION OF GROUND PROCESSING PROCEDURE AND SOFTWARE