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STUDY OF UNIVERSAL ALIGNMENT EQUIPMENT. REVISED.(U)
APR 80 A WEHMEYER, M BRODER, T BRADY F33657-79-C-0783
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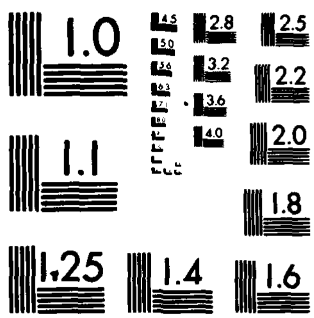


MICROCOPY RESOLUTION TEST CHART

Table IV-4

A-10 COST FACTORS FOR OPTICAL VS ELECTRONIC ALIGNMENT METHODS

ITEMS TO BE ALIGNED	ALIGNMENT FIXTURES AND INSTRUMENTS		NTDLE FOR FIXTURES $K		FAB COSTS FOR FIXTURES $K		ALIGNMENT FREQ PER AIRCRAFT IN 10 YEARS						TIME REQUIRED TO CHECK ALIGNMENT-MAN HOURS						TIME RQD TO ADJ. MT. MAN-HR	NEW T.O. PAGES	
							FACTORY		DEPOT		FIELD		FACTORY		DEPOT		FIELD				
	OPTICAL METHOD	ELECTRONIC METHOD	OPT	ELEC	OPT	ELEC	CHK	ADJ	CHK	ADJ	CHK	ADJ	OPTL	ELEC	OPTL	ELEC	OPTL	ELEC		OPTL	ELEC
HUD MT TO SIM. GUN	HUD MT OPTICAL ADAPTER	SIMUL. GUN MRP & MOD. HUD MT.	PAID	20	PAID	3	1	1	2	0.1	-	-	1.5	1.0	2.1	1.0	-	-	1.4	0	4
HUD-TO-GUN FLD CHK	HUD MASK PLATE	SAME	PAID	SAME	PAID	SAME	-	-	2	0	4	0	-	-	0.5	0.5	0.5	0.5	-	0	-
PAVE PENNY PYLON MT.	SIMULATED PYLON	SAME	PAID	SAME	PAID	SAME	1	1	2	0.1	0	0	0.5	0.7	1.0	1.2	-	-	4.0	0	3
PAVE PENNY POD MT.	SIMULATED POD	NEW SIM POD	PAID	10	PAID	5	0	0	2	0	3	0	-	-	1.0	1.2	1.0	1.2	-	0	2
SUU-23A GUN PODS	SUU-23A ADAPTER	NEW ADAPTER	PAID	10	PAID	5	0	0	0	0	20	20	-	-	-	-	1.7	1.9	0.5	0	4
IMU MOUNT	IMU MT ADAPTER	NONE RQD	15	10	9	-	1	1	1	0.3	2	0	1.0	0.5	2.0	1.5	2.0	1.5	2.0	10	8
FLIR MOUNT	FLIR MT ADAPTER	NONE RQD	15	5	9	-	1	1	2	1.0	4	0	1.0	0.5	2.0	0.5	2.0	0.5	2.0	12	10
RADAR MOUNT	RADAR MT ADAPTER	NONE RQD	15	5	9	-	1	1	2	1.0	2	0	1.0	0.5	2.0	0.5	2.0	0.5	2.0	13	10
SYSTEM EQUIPMENT & INSTRUMENTS	LASER, NEW TARGET BD	-	10	-	10	-	1	-	3	-	31	-	4.3		4.3		4.3		-	5	-
		LASER, OLD TGT BD	-	PAID	-	PAID	-	-	-	-	4	-		-		4.3		4.3	-	-	0
	1 AXIS LEVEL SENSOR SYS	2 AXIS LEVEL SENSOR SYS	-	100	3	15															
		AZ TRANSFER DEVICE	-	500	-	50															
SYSTEMS ENGINEERING	2 MEN, 6 MOS, $40/HR	2 MEN, 18 MOS	80	240	-	-															
			135	900	40	78														40	41

The F-15 gun must be replaced after a given number of rounds are fired, and it must be realigned when it is replaced. This accounts for the large number of gun alignment actions at the field level, and the large number of times that the target board must be set up. The A-10 requires no realignment when its 30 mm internal gun is replaced, because the gun is an interchangeable LRU.

Most of the mounts in the advanced bomber are assumed to be directly compatible with the electronic alignment instruments. RDT&E costs were estimated to accomplish designing alignment instrument surfaces into the mounts in order to make this possible for the electronic method. The absence of alignment adapters eliminates adapter development costs and minimizes alignment time.

There are several advantages of the electronic transfer alignment method that aren't included in this analysis. First, the time required to locate and gather the alignment equipment from warehouses is not considered, nor are warehouse costs counted. There are relatively few adapters needed for the electronic method. Second, the cost of dedicated factory work space for optical alignment is not counted. No special space is needed for the electronic method. Third, it is unnecessary to schedule times when other workers must be kept off the aircraft to accomplish electronic alignment. This eliminates a potential source of wasted man hours.

RESULTS

Tables IV-5 and IV-6 are sample computer printouts of the AFLSC model for aligning the mounts in the advanced bombers using the optical method and the electronic method respectively. Similar data were generated for the F-15 and A-10.

The data from these two tables are repeated and compared in Table IV-7 for the advanced bomber. Similar data are presented in Table IV-8 and IV-9 for the F-15 and A-10 respectively. The B-52 is discussed later.

The left portion of each table shows the RDT&E and production costs of the alignment adapters for each mount. The center portion of the tables lists the costs and labor to accomplish the alignment tasks at the factory, at the depot, and in the field for each mount. The right portion shows training costs and the costs to provide new technical orders and data. The training costs include purchase of one set of alignment adapters and instruments except for the optical equipment for existing aircraft, which is assumed to be sunk. The labor costs, training costs, and data costs constitute operations and support costs.

Tsble IV-5

B-XX OPTICAL ALIGNMENT

ACQUISITION AND 10 YEAR O&S COSTS
(ALL COSTS ARE IN THOUSANDS OF CONSTANT 1979 DOLLARS)

CONFIGURATION SUMMARY

ITEM	RDT&E	PROD	FACTORY	DEPOT	FIELD	TRAINING	TO & DATA	TOTAL
HUD MNTS	20.0	117.0	31.3	24.7	57.4	16.6	10.5	277.5
PDR ANTS	30.0	288.0	75.1	131.5	102.0	41.7	16.1	684.5
TF ANTNA	15.0	72.0	12.5	27.4	31.9	10.8	8.7	178.4
DPPLR MT	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
IMU-1 MT	15.0	81.0	18.8	32.9	25.5	11.4	10.1	194.7
IMU-2 MT	10.0	81.0	18.8	32.9	25.5	11.4	6.1	165.7
AHRS MT	15.0	63.0	18.8	14.2	9.6	8.2	8.1	136.9
FLIR MT	15.0	90.0	18.8	16.4	25.5	12.0	9.4	187.2
IR WARN	20.0	90.0	37.6	28.5	19.1	12.5	10.1	217.8
AOA SYST	10.0	20.0	6.3	2.7	0.0	10.6	5.1	54.7
MAG ALIG	10.0	45.0	4.4	5.8	3.5	5.6	6.1	80.4
FWD TAXI	15.0	225.0	26.9	47.1	137.1	36.2	15.1	502.4
AFT SYS	0.0	0.0	5.0	4.4	7.7	0.8	4.6	22.5
SUBTOTAL	175.0	1172.0	274.3	368.5	444.7	178.1	109.9	2722.5
ALIGN FX	15.0	63.0	0.0	0.0	0.0	7.0	4.8	89.8
TAXIS SS	0.0	27.0	0.0	0.0	0.0	3.0	1.2	31.2
SYS ENG	480.0	0.0	0.0	0.0	0.0	0.0	0.0	480.0
GRAND TOTAL	670.0	1262.0	274.3	368.5	444.7	188.1	115.9	3323.6

Tsble IV-6

B-XX NEW ELCTRONIC ALIGNMENT METHOD

ACQUISITION AND 10 YEAR O&S COSTS
(ALL COSTS ARE IN THOUSANDS OF CONSTANT 1979 DOLLARS)

CONFIGURATION SUMMARY

ITEM	RDT&E	PROD	FACTORY	DEPOT	FIELD	TRAINING	TO & DATA	TOTAL
HUD MNTS	29.0	162.0	43.8	35.6	82.9	24.1	14.5	391.9
RDR ANTS	19.0	0.0	62.6	109.6	82.9	7.3	12.9	294.3
IF ANTNA	10.0	0.0	9.4	21.9	25.5	2.1	7.9	76.9
DPPLR MT	5.0	6.0	0.0	0.0	0.0	3.0	2.0	16.0
IMU-1 MT	10.0	0.0	18.8	32.9	25.5	2.4	10.9	100.5
IMU-2 MT	10.0	0.0	15.7	27.4	20.7	1.8	5.7	81.3
AHRS MT	10.0	0.0	15.7	11.5	8.0	0.9	6.1	52.1
FLIR MT	10.0	0.0	15.7	13.7	20.7	1.5	7.4	69.0
IR WARN	13.0	0.0	31.3	23.0	15.9	1.9	7.7	92.8
AOA SYST	10.0	20.0	6.3	2.7	0.0	10.6	5.1	54.7
MAG 2AXI	5.0	0.0	4.4	5.8	3.5	0.6	4.1	23.4
SUBTOTAL	131.0	188.0	223.6	284.2	285.6	56.3	84.2	1252.9
2AXIS SS	100.0	135.0	0.0	0.0	0.0	15.0	1.6	251.6
AZ XFR	500.0	450.0	0.0	0.0	0.0	50.0	4.0	1004.0
SYS ENG	480.0	0.0	0.0	0.0	0.0	0.0	0.0	480.0
GRAND TOTAL	1211.0	773.0	223.6	284.2	285.7	121.3	89.8	2988.5

Table IV-7

ADVANCED BOMBER ALIGNMENT COSTS
USING EITHER OPTICAL OR ELECTRONIC ALIGNMENT METHODS

COSTS ARE IN THOUSANDS OF 1979 DOLLARS

MOUNT OR ITEM	RDT&E		PRODUCTION		FACTORY LBR		DEPOT LBR		FIELD LBR		TRAINING		T.O. & DATA		TOTAL	
	OPTL	ELEC	OPTL	ELEC	OPTL	ELEC	OPTL	ELEC	OPTL	ELEC	OPTL	ELEC	OPTL	ELEC	OPTL	ELEC
HUD MTS	20	29	117	162	31.3	43.8	24.7	35.6	57.4	82.9	16.6	24.1	10.5	14.5	277.5	391.9
RADAR ANTS	30	19	288	0	75.1	62.6	131.5	109.6	102.0	82.9	41.7	7.3	16.1	12.9	684.5	294.3
TF ANTENNA	15	10	72	0	12.5	9.4	27.4	21.9	31.9	25.5	10.8	2.1	8.7	7.9	178.4	76.9
DOPPLER MT	0	5	0	6	0	0	0	0	0	0	0	3.0	0	2.0	0	16.0
IMU-1 MT	15	10	81	0	18.8	18.8	32.9	32.9	25.5	25.5	11.4	2.4	10.1	10.9	194.7	100.5
IMU-2 MT	10	10	81	0	19.8	15.7	32.9	27.4	25.5	20.7	11.4	1.8	6.1	5.7	185.7	81.3
AHRS MT	15	10	63	0	10.8	15.7	14.2	11.5	9.6	8.0	8.2	0.9	8.1	6.1	136.9	52.1
FLIR MT	15	10	90	0	18.8	15.7	16.4	13.7	25.5	20.7	12.0	1.5	9.4	7.4	187.2	69.0
IRTV MTS	20	13	90	0	37.6	31.3	28.5	23.0	19.1	15.9	12.5	1.9	10.1	7.7	217.8	92.8
AOA MTS	10	10	20	20	6.3	6.3	2.7	2.7	0	0	10.6	10.6	5.1	5.1	54.7	54.7
MAD MT	10	5	45	0	4.4	4.4	5.8	5.8	3.5	3.5	5.6	0.6	6.1	4.1	80.4	23.3
FWD TGT BD	15	-	225	-	26.9	-	47.1	-	137.0	-	36.2	-	15.1	-	502.4	-
TGT BD AFT	0	-	0	-	5.0	-	4.4	-	7.7	-	0.8	-	4.6	-	22.5	-
SUB TOTAL	175	131	1172	188	274.3	223.6	368.5	284.1	444.7	285.6	178.1	56.3	109.9	84.2	2722.5	1252.8
OPTL ALIGN F.	15	-	63	-	-	-	-	-	-	-	7.0	-	4.8	-	89.8	-
LEVEL SENSOR	0	100	27	135	-	-	-	-	-	-	3.0	15.0	1.2	1.6	31.2	251.6
AZ XFR DEV	-	500	-	450	-	-	-	-	-	-	-	50.0	-	4.0	-	1004.0
SYS ENGR	480	480	-	-	-	-	-	-	-	-	-	-	-	-	480.0	480.0
TOTAL	670	1211	1262	773	274.3	223.6	368.5	284.1	444.7	285.6	188.1	121.3	115.9	89.8	3323.6	2988.5

- 240 AIRCRAFT (210 UE)
- 7 BASES

* 9 SETS OF INSTRUMENTS AND FIXTURES PLUS 1 SET FOR TRAINING

$26.09/HR LABOR ($15.18 IN FIELD)

Table IV-8

F-15 ALIGNMENT COSTS
USING EITHER OPTICAL OR ELECTRONIC ALIGNMENT METHODS

COSTS ARE IN THOUSANDS OF 1979 DOLLARS

MOUNT OR ITEM	RDT&E		PRODUCTION		FACTORY LBR		DEPOT LBR		FIELD LBR		TRAINING		T.O. & DATA		TOTAL	
	OPTL	ELEC	OPTL	ELEC	OPTL	ELEC	OPTL	ELEC	OPTL	ELEC	OPTL	ELEC	OPTL	ELEC	OPTL	ELEC
HUD MT	0	11	0	96	21.8	29.1	48.8	67.6	113.6	157.4	5.8	17.5	12.2	12.2	202.4	390.8
HUD CASE	0	0	0	0	5.1	5.1	13.2	13.2	30.6	30.6	2.6	2.6	12.2	12.2	63.6	63.6
20 MM GUN	0	15	0	72	7.3	8.7	29.1	32.9	450.8	503.3	22.4	31.9	57.8	57.8	567.4	721.6
INU MT	0	15	0	60	18.2	18.2	36.6	36.6	18.0	18.0	1.9	6.9	5.4	5.4	80.2	160.2
ANT MT*	0	15	0	16	9.5	9.5	112.7	112.7	0	0	3.2	11.2	5.4	7.8	130.8	172.2
ANT VERIF	0	15	0	60	5.1	5.1	24.4	24.4	28.4	28.4	1.6	6.6	7.7	7.7	67.2	147.2
AHRS GRU*	0	15	0	12	11.6	11.6	27.2	27.2	0	0	0	6.0	3.2	3.2	42.0	75.0
MAG AZ DET*	0	10	0	12	5.8	5.8	55.0	55.0	0	0	0	6.0	3.2	3.2	64.0	92.0
LC GYRO*	0	15	0	12	10.9	10.9	31.1	31.1	0	0	0	6.0	3.2	3.2	45.2	78.2
AOA SENSORS*	0	0	0	0	7.3	7.3	12.2	12.2	0	0	0	0.0	2.0	2.0	21.5	21.5
TGT BD/MAP	0	36	0	120	24.0	3.6	124.0	18.8	972.5	147.5	65.7	20.0	66.7	69.1	1252.9	414.8
SUB TOTAL	0	147	0	460	126.7	114.9	514.3	431.7	1613.9	885.1	103.3	114.7	179.1	183.9	2537.2	2337.1
LEVEL S.S	-	100	-	180	-	0	-	0	-	0	-	15.0	-	2.0	-	297.0
AZ XFR DEV	-	500	-	600	-	0	-	0	-	0	-	50.0	-	4.0	-	1154.0
SYS ENGR	0	320	-	-	-	-	-	-	-	-	-	-	-	-	0	320.0
TOTAL	0	1067	0	1240	126.7	114.9	514.3	431.7	1613.9	885.1	103.3	179.7	179.1	189.9	2537.2	4108.1

- 729 AIRCRAFT (720 UE)
- 450 AIRCRAFT ALREADY ALIGNED AT FACTORY
- * ADJUSTED AT FACTORY AND DEPOT ONLY
- 10 BASES (72 AIRCRAFT EACH)
- 12 SETS OF INSTRUMENTS AND FIXTURES PLUS 1 SET FOR TRAINING
- $26.09/HR LABOR ($15.18 IN FIELD)
- ALL OPTICAL EQUIPMENT COSTS ASSUMED TO BE SUNK

Table IV-9

A-10 NIGHT/ADVERSE WEATHER AIRCRAFT ALIGNMENT COSTS
USING EITHER OPTICAL OR ELECTRONIC ALIGNMENT METHODS

MOUNT OR ITEM	RDT&E		PRODUCTION		FACTORY LBR		DEPOT LBR		FIELD LBR		TRAINING		T.O. & DATA		TOTAL	
	OPTL	ELEC	OPTL	ELEC	OPTL	ELEC	OPTL	ELEC	OPTL	ELEC	OPTL	ELEC	OPTL	ELEC	OPTL	ELEC
HUD MT	0	20	0	6	15.1	12.5	21.7	10.7	0	0	0.1	3.0	3.4	3.4	40.3	55.6
HUD-GUN CHK	0	0	0	0	0	0	5.0	5.0	5.8	5.8	0.5	0.5	3.6	3.6	14.9	14.9
PYLON MT	0	0	0	0	23.5	24.5	12.0	14.0	0	0	0.0	0.0	3.0	3.0	38.5	41.5
POD MT	0	10	0	40	0	0	10.0	12.0	8.7	10.5	0.9	6.1	3.8	3.8	23.4	82.4
20 MM GUNS	0	10	0	40	0	0	0	0	128.2	139.9	6.2	11.9	13.7	13.7	148.1	215.5
IMU MT	15	10	72	0	15.7	13.0	13.0	10.5	11.7	8.7	10.5	1.1	5.7	5.7	143.6	49.0
FLIR MT	15	5	72	0	15.7	13.0	30.0	15.0	23.3	17.5	11.5	0.6	8.3	8.3	175.8	59.4
RADAR MT	15	5	72	0	15.7	13.0	30.0	15.0	11.7	8.7	10.8	0.5	7.1	7.1	162.3	49.3
TARGET BD	10	-	80	-	22.4	-	64.6	-	388.5	50.1	37.2	3.1	21.2	2.4	623.9	55.6
SUB TOTAL	55	60	296	86	108.1	76	186.3	82.2	577.9	241.2	77.7	26.8	69.8	51.0	1370.8	623.2
LEVEL SENSORS	0	100	24	120	-	-	-		-	-	3	15	-	-	27	235
AZ XFR DEV	-	500	-	400	-	-	-	-	-	-	-	50	-	-	-	950
SYS ENGR	80	240	-	-	-	-	-	-	-	-	-	-	-	-	80	240
TOTAL	135	900	320	606	108.1	76	186.3	82.2	577.9	241.2	80.7	91.8	69.8	51.0	1477.8	2048.2

- 200AIRCRAFT (192 UE)
- $26.09/HR LABOR ($15.18 IN FIELD)
- 6 BASES
- 8 SETS OF INSTRUMENTS AND FIXTURES PLUS 1 SET FOR TRAINING

The upper portions of Tables IV-7, IV-8 and IV-9 show costs associated with aligning the various mounts exclusive of those costs associated with the target sighting board and master reference plate, which are shown next. This is followed by a subtotal. Below the subtotal are costs associated with an optical alignment fixture for aligning the optical target board, costs for level sensors, costs for an azimuth transfer device, systems engineering costs, and total costs. Costs associated with the target board and master reference plate must be prorated among the various mounts to determine the actual costs to align any particular mount.

Data presented on these tables document results which were used to prepare Figure IV-1. This figure graphically illustrates the relative importance of the various cost factors.

For the advanced bomber, the RDT&E costs for the alignment fixtures (adapters) are not prominent cost factors. One can easily afford to spend added engineering effort to modify mount designs if it will eliminate alignment adapaters. Use of the electronic alignment method results in approximately 1 million dollars ($1M) in cost savings for alignment adapters and fixtures for the bomber program, on an alignment task that would otherwise cost $3.3M using the optical method.

The cost of operations and support is also reduced by nearly $0.5M by using the electronic alignment method instead of the optical method. The combined savings of fixtures (RDT&E plus production) and operations is $1.6M using the electronic method, but the assumed one-time costs to develop and procure alignment instruments add $1.3M back into the program for a net saving of only $0.3M. This saving is approximately 10 percent of the cost to perform the task optically.

As the bomber fleet leaves the factory, the alignment costs up to that time are essentially the same using either the optical or the electronic alignment method. This is shown in Figure IV-2. The reason that the electronic method is not superior at this point is because of the alignment instrument development costs incurred by this method. By the end of 10 years of field operation, the cost saving using the electronic method is $0.3M. This increases to $0.6M in 20 years operating time, as shown on Figure IV-2.

The development and production costs of the electronic alignment instruments are treated as fixed quantities in the data presented thus far, but in the analysis to be presented next, they are treated as variables. Returning momentarily to the data for Figure IV-1, the combination of $0.60M for RDT&E of the alignment instruments, $0.65M for production of 10 sets of these instruments, and $0.335M overall program cost savings for the electronic alignment method relative to the optical method, is $1.585M total.

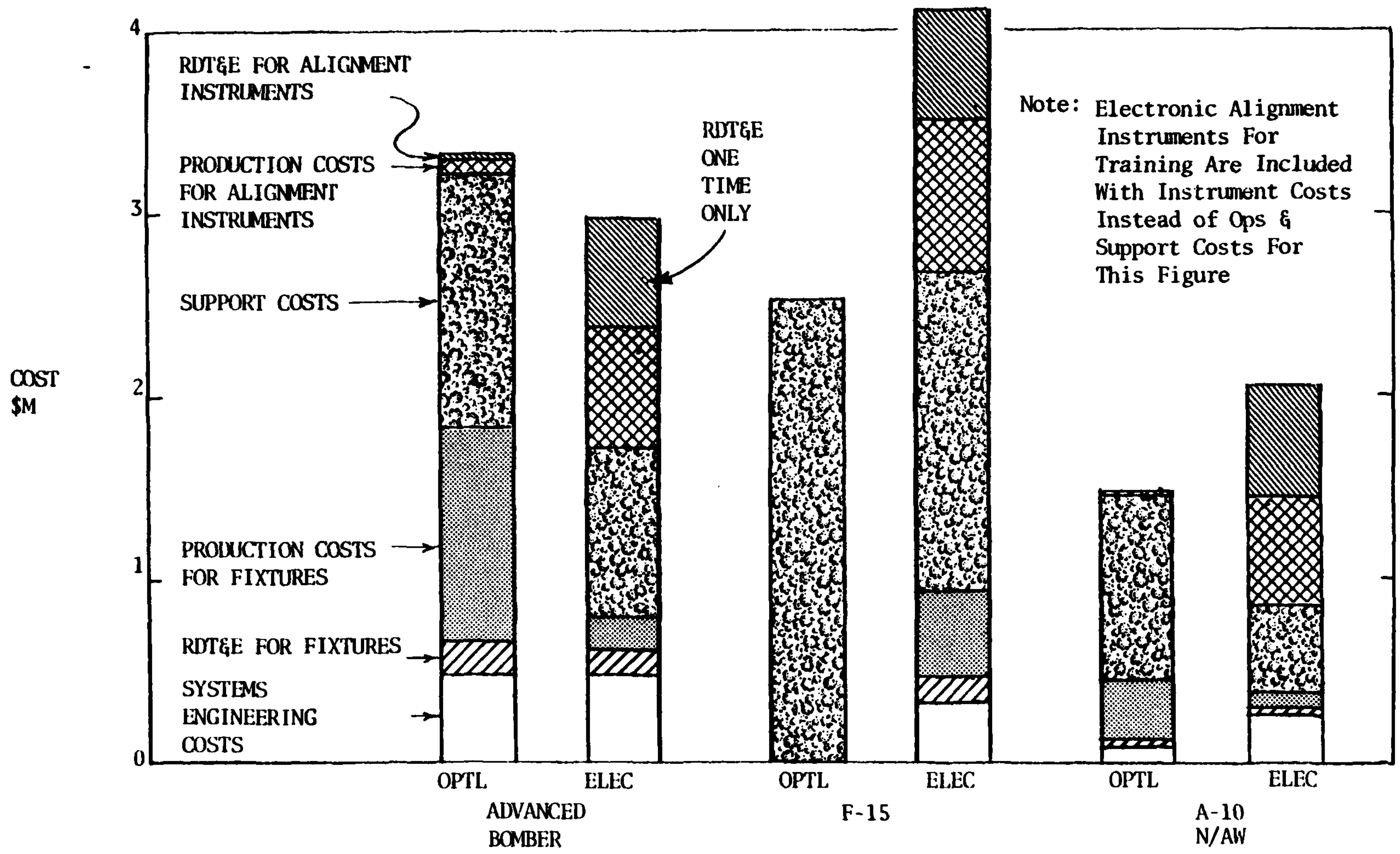


Figure IV-1 Cost Comparison For Using Either Optical Or Electronic Alignment Methods on Advanced Bomber, F-15, and A-10 Night/Adverse Weather Aircraft

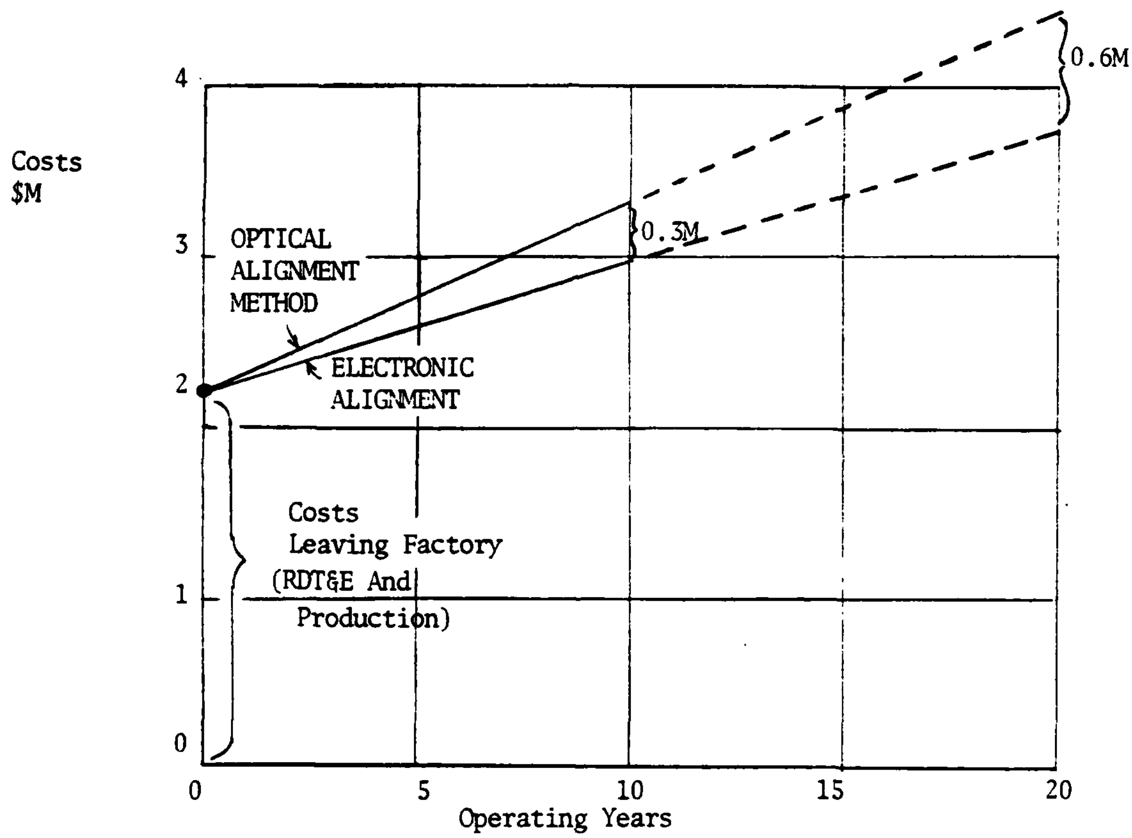


Figure IV-2 Alignment Costs For Advanced Bomber Fleet As A Function Of Time

Suppose that this $1.585M sum is kept constant, but the constituent parts are allowed to vary (i.e., instrument RDT&E costs, instrument production costs, and program savings). Suppose further that 11 sets of instruments are purchased instead of 10 so that one set will be available as a spare.

With these assumptions, the solid lines on Figure IV-3 show how these costs and savings may be apportioned. For the case assumed previously where $0.6M is invested to obtain instruments costing $65K per set, the program savings are about $0.27M (instead of the $0.335M mentioned above due to purchase of the spare set of instruments). The same amount of program savings ($0.27M) could be realized by investing $1.0M in RDT&E if one could obtain instruments costing $28K per set. This may be seen from Figure IV-3.

It is recommended that no more be invested in instruments than that which will result in positive cost savings on the first major aircraft program on which they are used. The actual savings that are realized may be less than those predicted in Figure IV-3 for the advanced bomber for several reasons. First, it may turn out that less alignment adapters can be eliminated than was assumed for this study. Second, the bomber may not be fitted with the wide variety of sensors that were assumed to be required, and this could result in a smaller overall alignment task. Third, the frequency of depot and field alignment could be less than assumed for this study, again reducing the size of the overall alignment task. Fourth, there may be inaccuracies in alignment task time estimates. Fifth, there may be other factors that could affect costs that are not presently recognized.

To allow for these uncertainties, it is recommended that no more be invested in alignment instruments (RDT&E and production) than that which will theoretically result in about $0.25M savings on a program the size of the advanced bomber program. This amount corresponds to the heavy solid line on Figure IV-3, and provides a margin for security to assure that some cost savings will result even if the $0.25M theoretical amount is not met. To assure a positive savings, one should stay below the heavy line shown on Figure IV-3.

Some portions of the area below the heavy line on Figure IV-3 are better than others. The dashed lines on Figure IV-3 show the combined theoretical savings on the first two major aircraft programs, assuming that they are both the same size. Figure IV-3 may be used as a guide when evaluating proposals from instrument developers to help decide which investment is best.

. Electronic Alignment Method
. Each Program Equivalent to Advanced Bomber Development Program
. Costs Include 1 Set of Spare Instruments Per Program

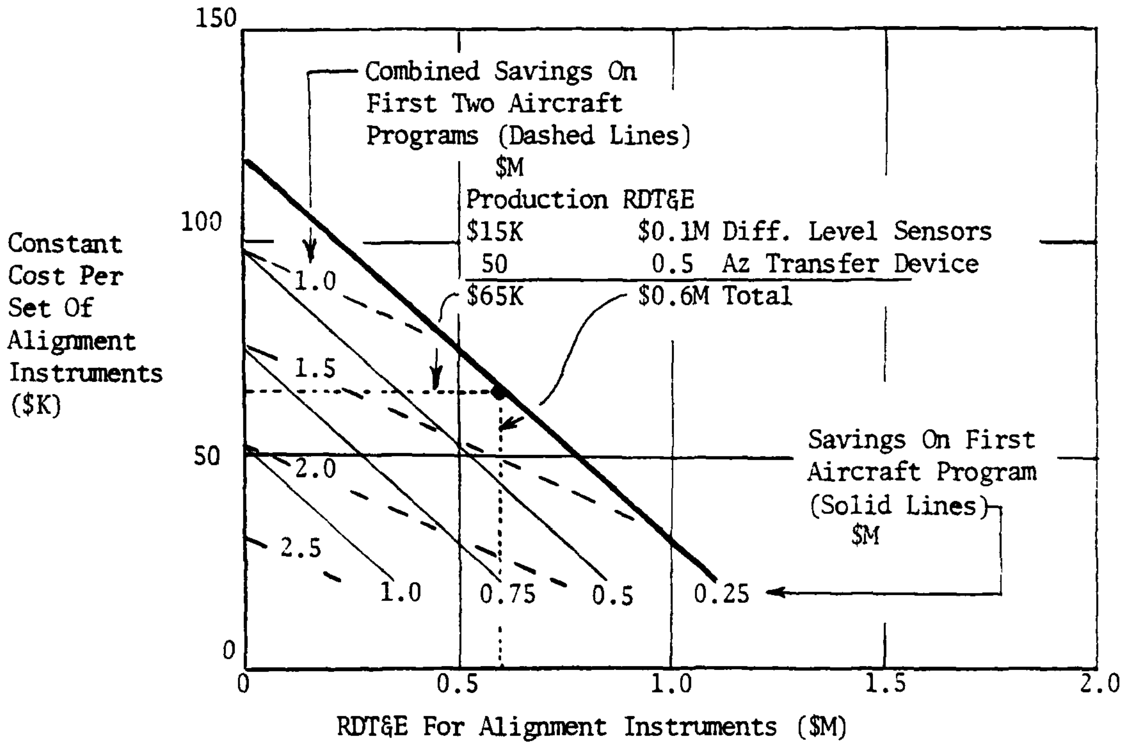


Figure IV-3 Relationship of Alignment Cost Savings To Alignment Instrument Development And Production Costs

Attention is turned next to level sensors. If an aircraft is not stabilized, differential pitch and roll level sensors are needed. It has been calculated from life cycle cost data taken from Table IV-7 for the advanced bomber that it is worth approximately $5K per set of electronic alignment instruments per hour of repetitive stabilization time that is saved by not having to stabilize the aircraft. Even if one assumes that only one hour is required to stabilize an aircraft, it is worth paying $5K extra per set of level sensors to obtain the differential reading capability in order to avoid stabilizing the aircraft. It is believed that this differential capability can be obtained at less cost than this, thereby making it a good buy. Of course, it is also important to select a design for the azimuth gyro transfer device which does not require aircraft stabilization or else this potential saving will be lost. An unstabilized aircraft has essentially zero average azimuth motion, making it unnecessary to use a differential azimuth gyro transfer device.

Returning to Figure IV-1 for consideration of the F-15, the data show that significant cost savings in operation and support costs could be realized by changing from the optical to the electronic method. However, the costs of the required adapters offset these savings, and the added costs for development and purchase of alignment instruments make it clearly unprofitable to change over to the electronic method.

For the night and adverse weather version of the A-10, Figure IV-1 shows that it is best to stay with the optical alignment method. Even if the development costs for electronic alignment instruments were already paid, it would still be only marginally profitable to change to the electronic method unless the alignment instruments were to cost much less than assumed for this study.

Due to the absence of a master reference plate in the B-52, it is necessary to first determine air vehicle coordinate axes which can then be transferred to a master reference plate. To establish coordinates, it is necessary to refer to widely separated jig points on the fuselage by optical means to establish the air vehicle coordinate frame. The very act of establishing this coordinate frame optically and transferring it first to the doppler mount outer frame, and then to the IMU-1 mount which is to serve as the master reference plate for alignment of other LRU's, necessitates accomplishment of the more difficult portion of the azimuth alignment tasks. From there, alignment of the other mounts in azimuth by mechanical transfer alignment is easy due to their close physical locations selected by Boeing to facilitate implementation of this method.

The use of an azimuth gyro transfer device instead of mechanical transfer devices would not reduce alignment time nor eliminate alignment fixtures needed for the level sensors. It would, however, increase alignment costs by approximately the costs of the azimuth gyro transfer devices, which are the bulk of the costs for the electronic alignment instruments. From Figure IV-1, it may be seen that these costs on other programs are substantial. By analogy, then, it is clear that the method proposed by Boeing, or a variation of it as proposed in this study, is superior to a changeover to an all-electronic alignment method. The use of clinometers as proposed by Boeing for pitch and roll transfer alignment is analogous to the use of electronic level sensors for electronically aligning the mounts in pitch and roll, and Boeing has been investigating use of electronic level sensors instead of clinometers.

CONCLUSIONS

It is concluded that development of a set of electronic alignment instruments for use on advanced aircraft is cost-effective, but present aircraft production programs reviewed should be left unchanged. A return of the investment for instrument development will occur along with a net cost savings on the first major aircraft program if the following limits are placed on instrument development and production costs:

	MAX RDT&E	MAX COST EACH
Differential Electronic Level Sensor System	$100K	$15K
Azimuth Gyro Transfer Device	500K	50K

On the next major aircraft program on which the instruments are used, the cost savings will be larger than the initial development investment if the program is the size of the advanced bomber program used in this study.

Figure IV-3 may be used to optimize the split in development and production costs for the instruments. If the costs are more than those listed above, or more than an equivalent set obtained from Figure IV-3, it is recommended to postpone development of the instruments for several years until technology is available to support achievement of these cost goals.

APPENDIX A

FORM LETTER

Dear Sirs:

The North American Aircraft Division of Rockwell International is soliciting information concerning ground support equipment which your company could develop and/or provide for use in aligning the mounts of alignment-sensitive avionics and other aircraft items. Attachment 1 gives background information and lists the type of information requested. Attachment 2 defines requirements and discusses the intended application of the instruments. Data are requested by 29 October 1979.

Jerry Davis

Attachments: a. Requested Data
b. TFD-79-466, Transfer Alignment Instrument Requirements, dated 21 September 1979

REQUESTED DATA

The North American Aircraft Division of Rockwell International is currently under contract to the Air Force to investigate the possibilities of a universal set of electronic installation alignment instruments. These instruments are intended for use as ground support equipment for aircraft and missiles to align the mounts for avionics sensors, guns, and other alignment-sensitive items. The study contract is based on experience gained on the B-1 program using commercial electronic level sensors as alignment instruments for pitch and roll, and an azimuth gyro transfer device that was originally designed for Army use to align field artillery guns relative to true north. The B-1 alignment concept is all-electronic, and involves transfer of alignment from a master reference plate within the aircraft to the mount to be aligned. No optical sightlines are used.

The contracted study involves analysis of the A-10, F-15, B-52, and a hypothetical new aircraft optimized to take maximum advantage of the alignment concept. Three sets of instruments are of interest:

1. Improved instruments of the type presently in use by Rockwell which could be provided quickly.

    a. Electronic level sensors
    b. Azimuth gyro transfer device

2. Instruments optimized for installation alignment on stationary aircraft.

    a. Electronics level sensor
    b. Azimuth gyro transfer device

3. Instruments capable of operating on either stationary or moving vehicles.

    a. Differential electronic level sensors
    b. Three-axis gyro transfer device

If the results of the Rockwell study predict cost effectiveness of universal alignment instruments as is anticipated, it is expected that the Air Force will fund a modest development of one or more of these 3 sets of instruments as a follow-on activity. These instruments have potential tri-service and NATO application in addition to use by aircraft and missile manufacturers.

TFD-79-466 contains tentative requirements and a discussion of their intended use. Interested companies are invited to modify or rewrite these requirements to take best advantage of their capabilities to achieve the desired alignment objectives. The following information is requested concerning those instruments which an interested company could provide:

1. Description of available equipment and/or new equipment which your company could readily develop.
2. Estimated lead time required for development and delivery
3. Estimate development costs (budgetary and planning) for normal and minimal lead time development.
4. Estimated costs for the first deliverable set
5. Estimated production costs for an initial buy of 10 sets
6. Other pertinent data

This is not a request for proposal, and information which is furnished must be furnished at no cost to Rockwell or to the Government. Data are requested by 29 October 1979. Questions of a technical nature should be directed to Arlo Wehmeyer at (213) 647-4025.

TFD-79-466

SERIAL NO.

TRANSFER ALIGNMENT INSTRUMENT REQUIREMENTS

PREPARED BY
A. WEHMEYER

APPROVED BY

G. A. Kinstler

G. KINSTLER, SUPERVISOR
AVIONICS INTEGRATION AND
SYSTEM REQUIREMENTS

DATE 21 September 1979
NO. OF PAGES i + 9

Rockwell International

North American Aircraft Division
P. O. Box 92098
Los Angeles, CA 90009
(213) 647-1000

TRANSFER ALIGNMENT INSTRUMENT REQUIREMENTS

TRANSFER ALIGNMENT CONCEPT

A master reference "plate" consisting of a machined level surface and an azimuth index ledge is used to define aircraft coordinates in pitch, roll, and azimuth. On new aircraft, the master reference plate may be designed into the aircraft on permament structure where it is conveniently available. This has been done on B-1 Aircraft No. 4. In older aircraft, the master reference plate may consist of an adapter on a mount (or some other attachment points on the aircraft) selected to serve as the master reference.

Mounts for new avionics sensors or other items may be designed to accommodate the alignment instruments directly without any adapters. Removal of the avionics sensor may or may not be required in order to accommodate the alignment instruments, depending on the design of the particular mount. For example, pitch alignment of the radar mount can be checked in B-1 Aircraft No. 4 with no adapters while the radar is either installed or not installed on its mount. Adapters for alignment instruments are needed on older mount designs to attach to the same (or equivalent) points as the item that is normally supported by the mount.

One method for implementing the transfer alignment concept involves positioning the alignment instruments on the master reference plate as indicated in Figure 1. Pitch and roll absolute readings are taken to assure that the aircraft is leveled to the central operating range of the instruments. The instruments are then nulled to the master reference plate either by mechanical leveling screws, by electronic means, or they are mathematically nulled by merely recording the prevailing readings. The instruments are then physically transported to the mount to be aligned (or checked). During this time, the aircraft must not be moved. The instrument readings at the new location are recorded and differenced from the readings at the master reference plate if the readings there were other than zero. The difference readings are the misalignment angles of the mount relative to the master reference plate.

In this manner, mounts can be aligned relative to each other by aligning all of them relative to the master reference plate. Like units can be replaced without realignment of the mounts provided that like units are in fact interchangeable. This is generally the case for modern avionics units.

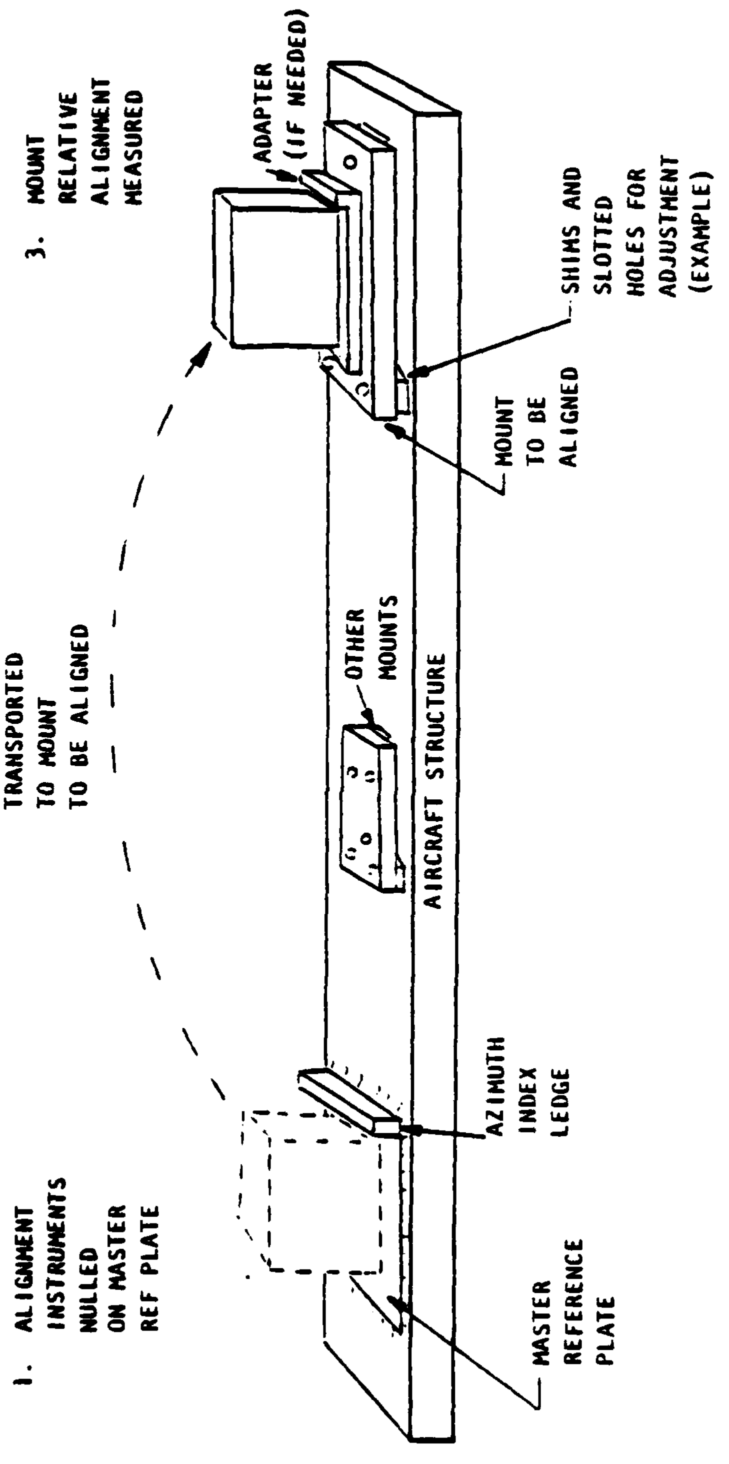


Figure 1. Transfer Alignment Concept

Although the concept as described requires that the aircraft be stationary, and possibly even stabilized by jack stands during alignment, this does not usually impose a difficult problem. A variation of the concept is discussed later which permits a limited degree of aircraft motion during alignment.

ELECTRONIC ALIGNMENT INSTRUMENTS IN USE ON B-1

Figure 2 shows the azimuth gyro transfer device that is presently in use for B-1. This is a stock item except for the base and its attached optical tower shown positioned in front of the theodolite. A pendulously suspended gyro is used to sense earth rotation and determine true north to an accuracy of ± 30 arc seconds.

Absolute accuracy is of no consequence for the transfer alignment application, and only repeatability is important. Repeatability errors are even smaller.

Elimination of the theodolite assembly on the top of the instrument would be helpful to reduce the instrument height and avoid the need for operator head room above the instrument, thereby permitting its use in crowded aircraft compartments. A whole angle readout of azimuth is not required since the device is used merely to measure the alignment difference between the master reference plate and the mount of interest. This difference will typically be less than a few degrees. A null-type angular sensor may be satisfactory.

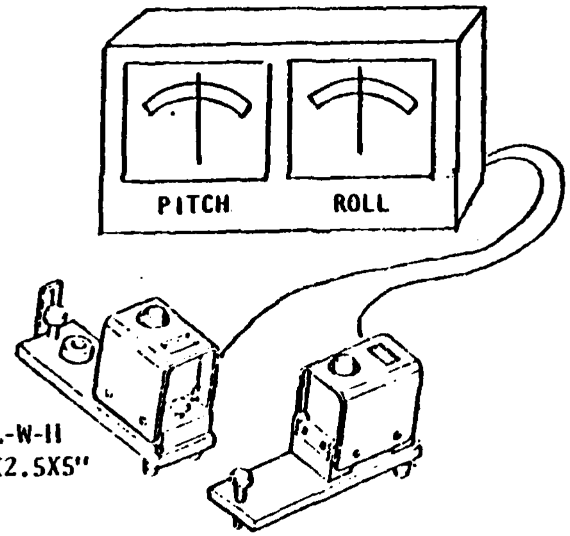
Simplified operation with a digital readout is desired. Due to normal turnover of personnel, operation should be sufficiently simple to permit effective use of the instrument by an untrained operator following instructions printed on the case.

Reduced sensitivity to aircraft vibrations would be helpful. Depending on aircraft supports, it is sometimes necessary to keep all workers off the aircraft while the present instrument is aligning. This can be costly. Reduced alignment settling time would also be helpful, since the instrument must be recycled following each trial-and-error mount alignment attempt.

The level detectors that are presently in use on B-1 work satisfactorily. Certain improvements appear attractive if the associated development costs are modest. Desired improvements include a digital readout, consolidation of sensors into one package, and optional use of leveling screws built into the sensor case.

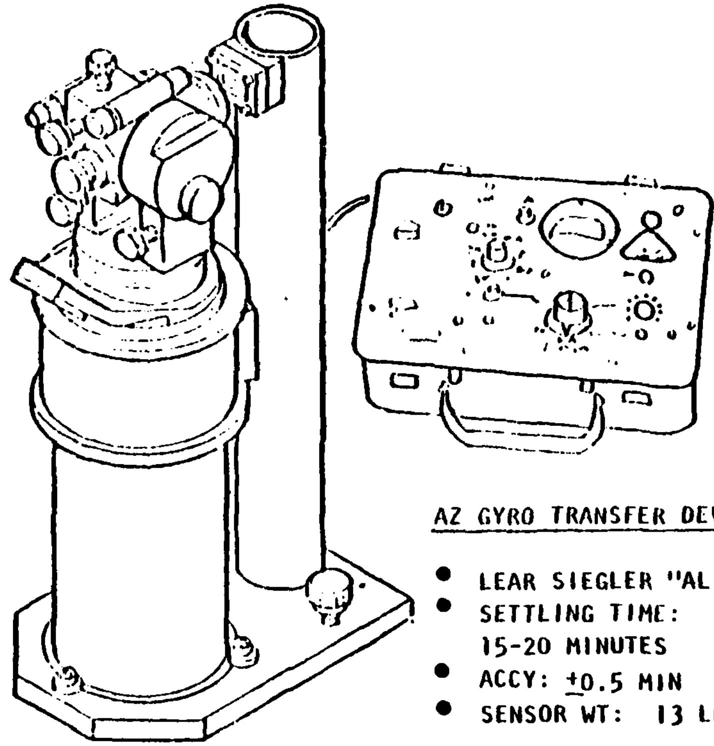
ELECTRONIC LEVEL DETECTOR

- BRUNSON INSTRUMENT COMPANY MODEL 477-2
- ACCURACY: BETTER THAN ± 0.5 MIN
- SENSOR WEIGHT: 3 LBS



L-W-H
8X2.5X5"

9.5" L
7.5" W
17.0" H



AZ GYRO TRANSFER DEVICE

- LEAR SIEGLER "ALINE"
- SETTLING TIME: 15-20 MINUTES
- ACCY: ± 0.5 MIN
- SENSOR WT: 13 LB

DESIRED IMPROVEMENTS

- CONSOLIDATED PKG ~5 X 5 X 5"
- BUILT-IN OPTIONAL LEVELING SCREWS

DESIRED IMPROVEMENTS

- SIMPLIFIED CONTROLS
- DIGITAL READOUT
- REDUCED PKG ~5 X 5 X 12"
- REDUCED VIBRATION SENSITIVITY
- 10 MINUTES SETTLING TIME

Figure 2. Aligmment Instruments Used On B-1

INSTRUMENTS OPTIMIZED FOR ALIGNMENT ON STATIONARY VEHICLES

AZIMUTH GYRO TRANSFER DEVICE

Inertial platform strapdown gyro technology is envisioned as one possibility for use in an optimized gyro transfer device. Up to 1.5 hours can be allowed (if necessary) once per day for the instrument to warm up and perform self-calibration on the master reference plate, and to determine earth rate components if needed. The instrument may then be carried (while operating) to the mount to be aligned where an instant readout of relative azimuth alignment is obtained. With the instrument still operating, the mount will be adjusted until correct readings are obtained. The instrument must tolerate moderate shocks such as operating on the mount while the mount is being tapped by a hammer to obtain correct alignment, after which time it is locked into position. After 0.5 hours of operation, the sensor may be momentarily returned to the master reference plate to null out the effects of gyro drifts.

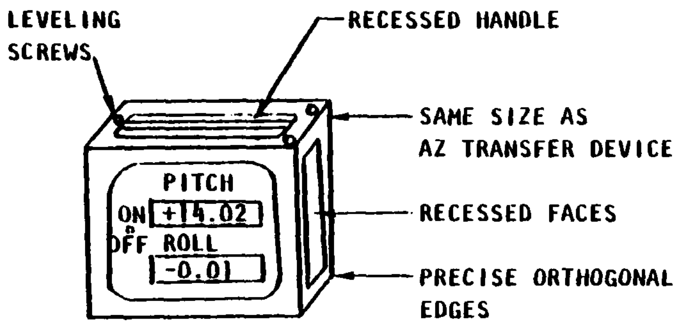
During the time that the gyro package is being carried from the master reference plate to the mount to be aligned, earth rate components must be appropriately taken into account to avoid excessive drift. The required compensation software will depend upon the gyro mechanization that is employed, and may depend on the instantaneous gyro orientation relative to the earth. The method to be selected by the developer is of special interest for concept evaluation. Permissible angular rates during transport of the gyros is also a matter of interest and concern.

The entire system should be sufficiently light to permit it to be easily carried about the aircraft. Otherwise, the electronics unit may remain stationary, provided that the cable length from the electronics to the sensor head is 100 feet or more to reach both ends of large aircraft while diverting about ground equipment and stands. This could be a problem also unless an exceptionally thin cable is used. Further requirements are shown in Figure 3.

The sensor head should be sufficiently small to fit recesses normally occupied by the smallest item whose mount is to be aligned. A small size is also desired to fit beside certain installed avionics items on a small extension of the mount. It is desired to standardize to a 3 or 4 inch cube, although a 5 or 6 inch cube or some other shape may be acceptable.

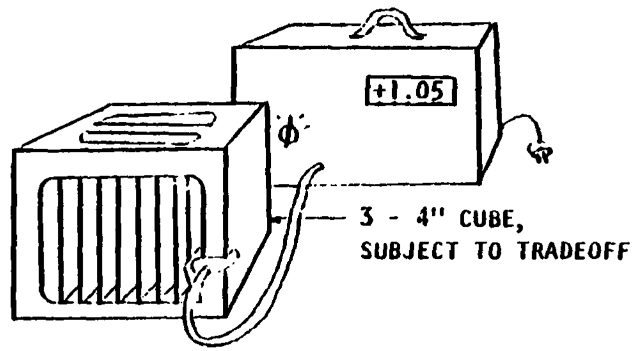
ELECTRONIC LEVEL DETECTOR

The general requirements for an electronic level detector are shown in Figure 3. The configuration that is shown is not intended to prohibit other designs which may be preferable in terms of cost or other factors.



TWO-AXIS ELECTRONIC LEVEL DEDECTOR

- PREFERRED CONFIG: SELF-CONTAINED UNIT (REMOTE CABINET ACCEPTABLE)
- OPTIONAL MECHANICAL LEVELING SCREWS
- DAY/NIGHT DIGITAL READOUT TO ± 99.9 MRAD
- ABS ACCY: ± 1 MRAD OR BETTER
- TRANSFER ACCY: ± 0.10 MRAD FOR CHANGES UP TO 10 MRAD EITHER AXIS
- POWER: FLASHLIGHT BATTERIES (115 VAC 400 HZ 1Ø MIL STD-704 OK)
- RUGGED DESIGN: MIL-T-28800 TYPE I CLASS II
- COST GOAL: UNDER $20K
- WT GOAL: UNDER 5 LBS
- MTBF: 1000 HR MIN, 4000 HR GOAL
- SIMPLE OR BUILT-IN TEST & CALIB.
- OPERABLE BY UNTRAINED PERSONNEL



AZIMUTH GYRO TRANSFER DEVICE

- PREFERRED MECH: NON-GYROCOMPASSING (GYROCOMPASSING TYPES NOT RULED OUT)
- PITCH & ROLL TRANSFER: FALLOUT CAPABILITY
- DAY/NIGHT DIGITAL READOUT TO ± 99.9 MRAD
- WARMUP/CALIB: 1.5 HR INITIAL, 10 SEC RESET
- TRANSFER ACCY: ± 0.10 MRAD OVER ± 10 MRAD RANGE & 0.5 HR GYRO DRIFT TIME
- PWR: 400 HZ 115 VAC 1Ø MIL-STD-704
- COOLING: SELF-CONTAINED
- RUGGED DESIGN: MIL-T-28800 TYPE I CLASS II
- COST GOAL: UNDER $50K
- WT GOAL: UNDER 30 LBS
- MTBF: 500 HR MIN, 2000 HR GOAL
- BUILT IN TEST AND CALIBRATION CAPABILITY
- OPERABLE BY UNTRAINED PERSONNEL

Figure 3. Instruments Optimized for Alignment

An electronic level detector is desired for pitch and roll even if the azimuth transfer device provides three-axis transfer alignment capability. It is desired because of its expected ease of operation, low cost, and good accuracy. It can be used to align one mount in pitch and roll while the azimuth gyro transfer device is used to complete the alignment on another mount.

Transfer of pitch alignment may include deliberate introduction of a bias angle to account for expected airframe deflections in flight. This bias angle must not affect roll transfer alignment accuracy provided that both are within 10-20 milliradians of the vertical.

INSTRUMENTS OPTIMIZED FOR USE ON EITHER STATIONARY OR MOVING VEHICLES

THREE AXIS GYRO TRANSFER DEVICE

If a suitable alignment instrument of low cost can be designed for use on aircraft that are aboard aircraft carriers at sea, the same unit may be used on the flight line or assembly line without bothering to stabilize the aircraft. This expanded market will promote commonality and may reduce unit costs. On the other hand, if high costs are involved to make the system work aboard an aircraft carrier, then a separate system will likely be developed exclusively for carrier applications.

Two gyro packages (3 axes each) are required for use on moving vehicles, as illustrated on Figure 4. Initially, both are placed side by side on the master reference plate and are synchronized to minimuze relative drift between them. While they are still operating, one unit is transported to the mount to be aligned or checked, and the other remains on the master reference plate. The difference readings in pitch, roll, and azimuth are the relative misalignment angles.

DIFFERENTIAL ELECTRONIC LEVEL SENSORS

A differential electronic level sensor is desired to supplement the 3-axis gyro transfer device. The differential level sensor has the potential advantages of low cost, zero warmup time, and indefinite operating time capability (no gyro drifts) at the mount which is being aligned. It is expected to be operable on unstabilized aircraft, but not on aircraft aboard carriers at sea. It may be used to align one mount in pitch and roll while the 3-axis gyro transfer device is ued to complete the alignment on another mount.

The differential level sensor employs one sensor head on the master reference plate and one sensor head on the mount to be aligned. Each head has two sensors so that both pitch and roll measurements can be made without moving the sensor heads.

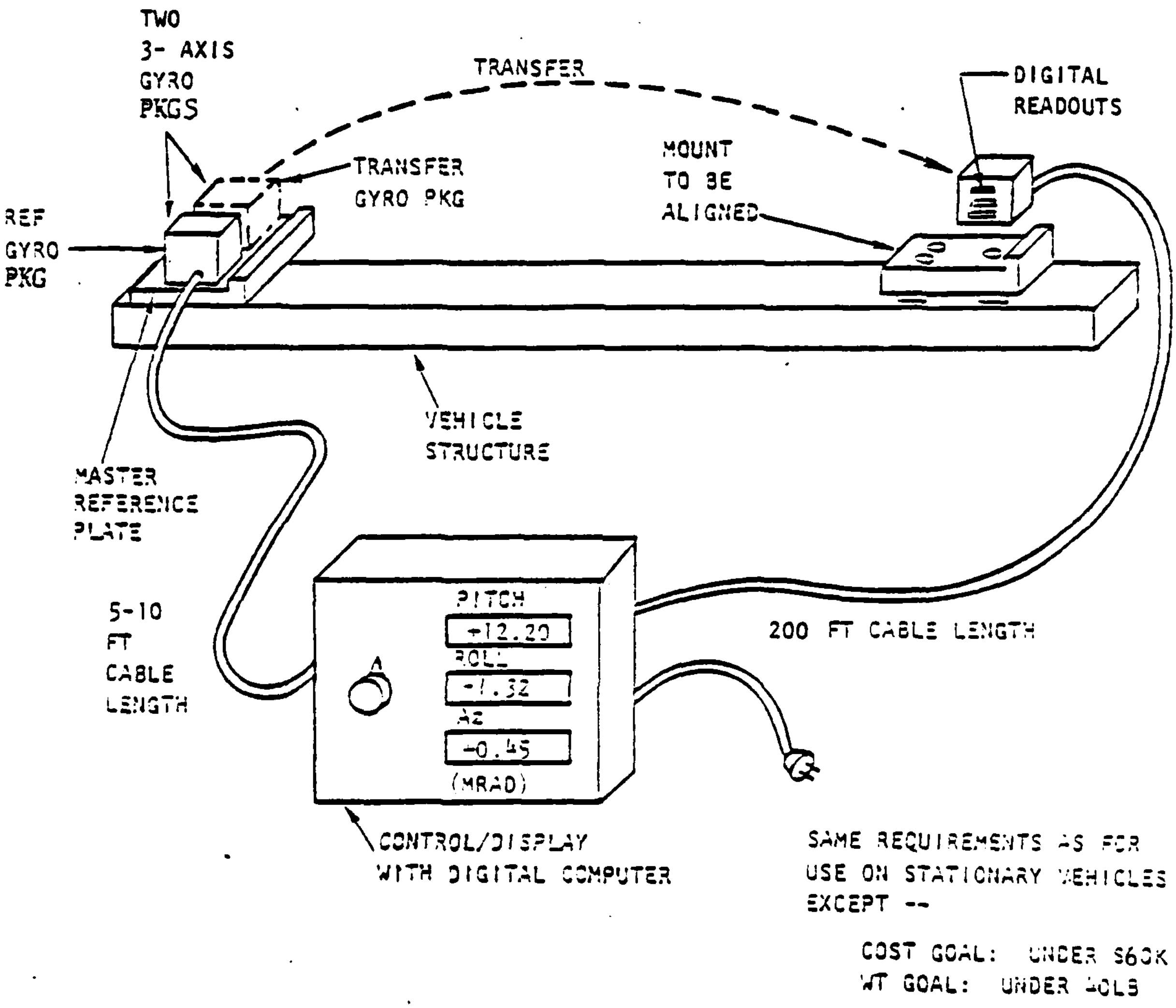


Figure 4.
Three-axis Gyro Transfer Device for Use on Moving Vehicles

After a mount has been aligned to the master reference plate in pitch and roll, the differential level sensor can be used to determine approximate azimuth alignment, provided that (a) the aircraft can be moved in pitch, (b) the instrument has low cross-axis sensitivity, and (c) the instrument has good sensitivity. If the aircraft can be moved ± 3 degrees in pitch, a differential roll measurement accurate to ± 0.1 milliradians is adequate to detect an azimuth misalignment angle of ± 1 milliradian. This concept may find application at remote sites where infrequent operations may not justify the cost of the 3-axis gyro transfer device.