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AN OPERATIONAL EVALUATION OF THE IBM 650 COMPUTER FOR AIR TRAFFIC CONTROL

FOR LIMITED DISTRIBUTION

by

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OF THE IBM 650 COMPUTER
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SUMMARY

This report describes an operational evaluation of an IBM 650 computer installed in the Indianapolis Air Route Traffic Control Center. The computer was used to prepare flight progress strips for the controller's display boards.

Flight plans received by the Air Route Traffic Control Center were encoded on punched cards and these cards were used as input to the 650 computer. By use of a stored program, the computer analyzed each flight plan; determined which fixes the flight would pass over, or near; computed the estimated time of passing these fixes, and organized the data for printing on flight progress strips in the proper format. The output of the computer, in the form of punched cards, was used in a 407 accounting machine to print flight progress strips.

The average time for processing flight plans by the computer where the route of flight was via airways was 7.39 seconds. The average processing time for direct-route flight plans was 17.32 seconds. The average total time from receipt of a flight plan at the Center until the flight strips were displayed in front of the controllers on the control boards averaged 4 minutes 21 seconds. As operated in the Indianapolis Center area, the processing rate was 81.6 flight plans or 311.3 flight progress strips per hour. However, the theoretical maximum processing rate of the system could be 6.6 flight plans per minute or 396 flight plans per hour. A comparison of processing flight strips manually is included in the report.

In general, the reliability of the system and the accuracy of the processed data were excellent. The type size of the data on the flight progress strips was too small for best use on the flight progress boards.

The IBM 650 computer system which was used in the Indianapolis Air Route Traffic Control Center from February to December, 1957, did not have adequate storage capacity for any further expansion of data processing. It since has been replaced by an IBM 650/RAMAC system which is to be evaluated also.

INTRODUCTION

This report describes an operational evaluation of the IBM 650 computer installed in the Air Route Traffic Control (ARTC) Center, Indianapolis, Ind. This computer was installed in November 1956, and placed in operational use from February to December, 1957. It since has been replaced with a larger computer having more storage capacity, the IBM

650/RAMAC. The FAA Technical Development Center (TDC) conducted an evaluation of this computer system based on data gathered during the period from September 5 to November 5, 1957.

EQUIPMENT

The IBM 650 computer system included the following equipment:

1. IBM 826 typewriter card-punch units, 4 each.
2. IBM 650 console unit.
3. IBM 655 power unit.
4. IBM 533 read-punch unit.
5. IBM 407 accounting machine.

The 826 typewriter card-punch units, shown in Fig. 1, were used to encode flight plan data on IBM 80-column punched cards. Flight plans were received from aircraft operators via voice interphone circuits, and assistant controllers typed the flight plan data on the 826 typewriter card-punch units. The typewriter unit provided a written record on a sheet of paper for visual checking by the operator at the same time the card was being punched. The data also were typed on the top edge of the card for easy checking of the information punched in columns on the card.

The 650 console, illustrated in Fig. 2, is a medium-size, digital computer including a calculating unit, control unit, and magnetic memory drum. The program of instructions for processing flight plan data was stored on the drum. When a flight plan was inserted into the computer, a detailed step-by-step program was followed to determine the fixes over or near which the flight would pass; the time of passing these fixes was computed; and the flight plan data for printing on the strips was organized. A complete description of the programming for the IBM 650 computer is contained in another report.[1] The 655 power unit supplied power for the 650 console and the 533 unit.

The 533 read-punch unit, illustrated in Fig. 3, is an input/output equipment connected directly to the 650 console. The flight plan cards received from the 826 typewriter card-punch units were fed into the input hopper of the 533 unit, and output from the 650 computer was provided on punched cards in the output hopper. One IBM 80-column card was punched out

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[1] Gilbert B. Harwell, Charles E. Dowling, Jr., and Fred S. McKnight, "Programming the IBM 650 Computer for Preparation of Flight Progress Strips in CAA Air Route Traffic Control Centers," Technical Development Report No. 346, March 1958.

on this unit for each fix required in the Indianapolis Center area. These output cards contained all of the necessary information for printing of the flight progress strips on the 407 printer.

The 407 accounting machine printer, shown in Fig. 4, is capable of printing 150 lines, or 50 flight progress strips, per minute. Perforated paper was used with appropriate blocks of information on the strips enclosed in preprinted lines. The output strips were cut, inserted into strip holders, and delivered to the flight progress boards by runners.

DATA PROCESSING REQUIREMENTS

To determine the size of the job to be done in processing flight plans at the Indianapolis Center, a detailed analysis was made of flight plans filed with the Center for the months of September and October, 1957. The average number of fix postings prepared daily was 4,289. On the peak day, 6,274 strips were prepared and on the lightest day, 2,490. During September, four days of relatively heavy traffic under IFR weather conditions were selected for more detailed analysis of the types of flight plans processed. Fix postings during these four days were between 5,110 and 5,851. Analysis of these days indicated that peak periods of traffic occurred between 1000 and 1300 EST. During this 3-hour peak period on these four days, a total of 12 hours, the data analysis indicated the following:

Flight Plan Rates

Total number of flights operated in the IND area in the 12-hour period	1,349
Average number of flights per hour	112
Maximum number of flights per hour	149
Minimum number of flights per hour	88

Type of Flight Plans by Route

Number of flights via airways	1,080	(80.1 per cent)
Number of flights via direct routes	208	(15.4 per cent)
Number of flights via combination airway and direct routes	61	(4.5 per cent)

Type of Flight Plans by Operator

Number of air carrier flights	704	(52.2 per cent)
Number of military flights	457	(33.9 per cent)
Number of civil itinerant flights	188	(13.9 per cent)

An analysis also was made of more than 15,000 flight progress strips used by the Indianapolis Center for more than 4,000 flights to determine the average number of fix postings required per flight. This analysis showed the following:

Average number of strips for flights via airways	3.88 strips
Average number of strips for flights via direct routes	3.94 strips
Average number of strips for flights via combination airway and direct routes	2.26 strips

Applying the latter averages to the proportion of flights operating via the various types of routes, it was determined that an overall average of 3.815 flight progress strips were required per flight plan.

An analysis of 106 flight plans was made to determine the distribution of flight strips required per flight plan, with the frequency of occurrence. These data are shown in Table I.

TABLE I

FLIGHT STRIP DISTRIBUTION PER FLIGHT PLAN

Number of Strips per Flight	Number of Flight Plans (Frequency of Occurrence)
1	11
2	28
3	32
4	18
5	9
6	6
7	2

Thus, 28 flight plans required two flight progress strips, 32 flights required three flight progress strips, and so forth. This distribution follows the Poisson random occurrence rate.

A further analysis of the 1,349 flights operating during the 3-hour peak periods on the four relatively busy days indicating the following rates of entry of flights into the Indianapolis area, is shown in Table II. The actual rate and the predicted random rate are based on the Poisson distribution.

TABLE II

RATE OF FLIGHT ENTRY

Number of Flights Entering the Area in a Given Minute	Actual Frequency of Occurrence - Number of Times	Poisson Distribution - Number of Times
0	171	111
1	231	207
2	127	194
3	82	121
4	41	57
5	29	21
6	13	7
7	9	1
8	7	1
9	6	1
13	1	
14	2	
18	1	

For example, 127 times, during the 720-minute period analyzed, two flights entered the Indianapolis area during the same minute. Twenty-nine times, during this same period, five flights entered the area during the same minute and, on one occasion, 18 flights entered the area during the same minute. As can be seen, the demand rate for processing flight plans is random and follows approximately a Poisson distribution. The average entry rate was 1.875 flights per minute during these 12 peak hours.

The peak demand rate for flight progress strips occurred in the Charleston sector which since has been divided into two sectors. An analysis of a 360-minute period is given in Table III.

TABLE III

PEAK DEMAND RATE FOR FLIGHT PROGRESS STRIPS

Number of Strips Required per Minute Based on Rate of Flights Entering the Charleston Area	Frequency of Occurrence-Number of Times
0	137
1	117
2	70
3	30
4	1
5	4
6	1

Thus, no strips were required for new flights entering the sector for 137 individual minute periods during the 360 minutes analyzed. One strip per minute was needed for 117 minutes of the 360, two strips per minute for 70 minutes of the 360, and so forth. This distribution again is Poisson, and averaged 1.05 strips per minute, or 63 strips per hour for this sector.

PROCESSING RATES

Time studies of the various steps in processing the flight plan data in the Indianapolis Center by use of the IBM 650 computer were made by observers using stop watches and Esterline-Angus recorders. For comparison, measurements also were made in the Indianapolis Center of the time required for processing flight plans manually, with assistant controllers preparing strips by hand. At the time these data were taken, assistant controllers prepared flight progress strips on the backside of Pittsburgh-type boards. Measurements also were made of a simulated centralized flight data position (FLIDAP) operation. The results of these measurements follow.

IBM 650 Computer System.

The time spent by personnel in performing various tasks for processing flight plans with the 650 computer system was recorded over a period of several days. These times then were averaged and are shown in Table IV.

The average time required by the 650 computer unit to process a flight plan was determined by processing a sample of 1,732 flight plans. These flight plans were typical of those handled by the Center and had a distribution by type of route, operator, and so forth, corresponding to the detailed analysis of flight plans on the four days in September 1957 referred to previously. The airway flights required an average processing time of 7.39 seconds; the direct route flights, 17.32 seconds; and the combination airway/direct route flights, 11.39 seconds.

The personnel complement assigned on an IFR day for the computer system processing was 11 men, having duties listed in Table I. From this table, it can be seen that one computer operator required an average of 44 seconds per flight plan for his handling. This included inserting the input card in the 533 unit; depressing several switches to start the computing cycle, the processing time in the 650 computer unit, the removal of output cards from the 533 unit; and the insertion of these cards in the 407 printer and depressing button switches to start operation of this machine. Since only one man was assigned to this position, the maximum capacity of the system was one flight plan each 44 seconds or 1.36 flight plans per minute (5.19 flight strips), or 81.6 flight plans per hour (311.3 flight strips). Thus, with the entire operation conducted by 11 men, an average of 7.4 flight plans or 28.3 flight strips per hour were produced per man using the 650 computer system. By assigning two men to the operation of the computer and printer, that is, one man assigned to the computer console and the other to the printer, it would have been possible to cut the handling time in half and double the rate of output.

TABLE IV

PROCESSING TIMES - IBM 650 COMPUTER SYSTEM

Operation	Average Time per Flight Plan (seconds)
826 Operators (4 men assigned)	
1. Copying flight plan on 826 punch-card unit.	40
2. Completing and checking punched card for use in the computer.	12
Runners (3 men assigned)	
3. Delay till picked up by runner.	5
Runner's time to computer input unit.	10
Computer Operator (1 man assigned)	
4. Insertion of cards in 533 input unit. Including delays.	10
5. 650 computer processing time.	9
6. Handling of output cards from 533 output unit to 407 printer including delays.	20
7. 407 printing time.	5
Strip Sorters and Stuffers (3 men assigned)	
8. Removal of strips from printer, sorting and inserting in holders.	90
Runners (same 3 runners as above)	
9. Delivery by runner to D board, including return of runner to computer room.	60

Total time required per flight plan - 4 minutes 21 seconds

The ultimate limiting factor in the system was the processing time of the 650 computer and its associated 533 input/output unit, provided that sufficient personnel were added to all of the operations to operate up to this level. In the Indianapolis area, since the average flight plan required 9.08 seconds of computer processing time and 3.815 strips, the theoretical maximum flight plan processing rate would be approximately 6.6 flight plans per minute (25.18 strips per minute), or 396 flight plans per hour (1,510 strips per hour). To operate at this rate, it is estimated that the following personnel listed in Table V would be required:

TABLE V

PERSONNEL REQUIREMENTS FOR THEORETICAL MAXIMUM FLIGHT PLAN PROCESSING RATE

Operation	Minimum Number of Personnel Required
826 operators	10
Runners	8
533/650 operator	1
407 operator	1
Sorters and stuffers	11
Total	31

Thirty-one personnel in this maximum capacity operation would have produced an output of 48.7 strips per hour per man.

The actual number of flight plans processed manually and by the IBM 650 computer during the peak 3-hour periods of the 4 busy days mentioned previously is shown in Table VI.

TABLE VI

FLIGHT PLANS PROCESSED PER HOUR

Hours EST		10-11	11-12	12-13	Total
September 9, 1957	IBM 650	62	57	64	183
	Manual	51	34	39	124
September 10, 1957	IBM 650	55	58	57	170
	Manual	84	62	50	196
September 11, 1957	IBM 650	57	54	52	163
	Manual	60	34	44	138
September 12, 1957	IBM 650	36	35	59	130
	Manual	113	74	58	245

Total flight plans processed on IBM 650 - 646

Total flight plans processed manually - 703

The average number of flight plans processed by the IBM 650 computer during the 12 hours (Table VI) was 53.8 flight plans per hour, with a maximum of 64 per hour. During these four days, the IBM 650 computer system was staffed with 11 men. During the above periods, no special efforts were made to process all possible flight plans with the IBM equipment.

The flight plans which were processed manually were analyzed, and it was determined that 296 (23.7 per cent) of the 703 flight plans could not have been processed by the computer. The reasons for this were:

1. The route of flight was excessive in length. The IBM 650 computer as programmed was capable of accepting on one input card a departure fix, a maximum of four en route fixes, and the destination fix. A special operation could be performed when receiving a long route of flight that would permit the computer to process the flight plan for the Indianapolis area with the additional route printed on the strips. To accomplish this, the IBM 826 typewriter card-punch operator could copy the first portion of the flight plan normally on the first card; then, by the use of a shift key, he could insert a second card on which could be typed up to 25 additional letters or numbers for extended routes. The second card would be fed only into the IBM 407 printer with the output cards from the IBM 650 computer and the additional route information would be printed on the flight progress strips. However, if more than five fixes were used to define the route of flight inside the Indianapolis area, this second card printing could not be used. Of the flight plans that could not be processed by the computer, 7.35 per cent were in the last category.

2. Successive fixes filed in a direct-route flight plan were too far apart. This group amounted to 6.9 per cent. The program for the IBM 650 computer would accept successive direct-route fixes not more than 223 miles apart. Proper flight-plan filing would have eliminated most of these since fixes defining the route of flight should not be more than 200 miles apart.

3. The point of entry was an excessive distance from an entry fix (2.15 per cent). If an estimate from an adjacent Center was specified as more than 15 miles from a recognized entry fix outside the Center's area, the computer would not accept the flight. An example of this would be a flight plan on an eastbound flight from the St. Louis Center estimated to pass 20 miles north of Vandalia en route to Terre Haute.

4. Secondary fixes specified in the route of flight which were not included on the airway tables in the program (7 per cent). Available drum storage space did not permit storage of all minor secondary fixes or intersections which were used occasionally.

5. Departure points within the Center area which were not programmed (0.3 per cent). These were normally smaller off-airway airports.

Flight plans that could have been processed by the IBM 650 computer system, but were processed manually, included:

1. Flight plans requiring only one strip (3.39 per cent).

2. Flight plans requiring only two strips (12.64 per cent).

3. Flight plans filed by the pilot in the air (6.9 per cent).

4. A miscellaneous group (46.7 per cent) including time-critical flight plans requiring three or more strips, approval requests, and flight plans filed on interphone lines not connected to the 826 operators.

There were only eight military mission flights encountered during the peak periods analyzed. This amounted to 0.59 per cent of the traffic. Of these eight military missions, only two flights, or 0.15 per cent of the total traffic, required strip preparation upon receipt. The other six flights were mission departures within the Indianapolis area, and strips had been prepared previously for these flights during periods of low activity.

From the traffic analyzed, the IBM 650 computer could have processed 92.33 per cent of the flight plans received in the Indianapolis ARTC Center area.

Manual Preparation on Center Boards.

For purposes of comparison, the activities of assistant controllers processing flight plans on the Pittsburgh-type (two-side operation) flight progress boards in the Indianapolis Center were measured during periods of heavy IFR traffic. Data were recorded during 24 one-hour periods. Sixty-one per cent of the assistant controllers' time was devoted to receiving flight plans, preparation of flight strips, and reloading strip holders. On the average, 46 seconds was required to prepare each strip during IFR weather. Thus, one assistant could prepare 47.7 strips per hour on the basis of spending 61 per cent of his time on this task.

FLIDAP (Flight Data Position) Operation.

Tests also were conducted on a simulated FLIDAP operation. Experienced assistant controllers were given flight plans aurally, and measurements were made of the time for processing the flight plan and producing the strips required at the Center.

The average time for preparation of each flight progress strip with this mode of operation was 36 seconds. Multiplying this by the average 3.815 strips required per flight plan, an average of 2 minutes 12 seconds would be required per flight plan. Assuming that an assistant at a FLIDAP position could work productively 90 per cent of the total time available, one man could produce 90 strips per hour, or process 23.6 flight plans per hour. However, runners also would be required to distribute flight strips from the FLIDAP positions. Based on experience with the IBM 650 equipment, it is estimated that a runner could deliver strips and stuff blank, returned holders at the rate of approximately 54 flight plans per hour or 203 strips per hour. The actual productivity of flight strips per man with the FLIDAP system would be approximately 60 strips per hour.

CAPACITY

Both the IBM 650 and manual (Pittsburgh boards) systems described above have a maximum capacity. Theoretically, the FLIDAP system has no maximum capacity provided no limitation exists in adding more operating positions and personnel.

In the case of the IBM 650 operation, the capacity of the system is limited, as shown under processing rates, to approximately 400 flight plans per hour with the computer programming used and the environmental conditions existing in the Indianapolis area.

In the case of the manual, Pittsburgh-board-type operation, it is difficult to determine the maximum capacity since it is affected by several factors. Normally a sector is staffed by one assistant controller on the back side of the board. It has been shown that the processing rate as well as the capacity of this one man in the Indianapolis Center is approximately 12.4 flight plans per hour, or 47.7 strips per hour based on spending 61 per cent of his available time on these duties. With 13 sectors operating, 13 assistants could process about 161 flight plans per hour (620 strips per hour) for the Center. During peak periods, it is the practice to assign more than one assistant to a sector to keep up with the workload. Due to physical limitations in working space and interphone equipment, however, it is not possible to carry this to the point of unlimited expansion. Assuming that one additional assistant could be assigned per sector, the practical operating capacity of the manual system would be improved considerably.

LEAD TIMES

One other aspect of the processing rates of flight plan data is the lead time required for filing flight plans to insure that the flight strips will reach the control boards at the proper time. Air traffic flow is random in nature, and various studies have indicated that in general it follows a Poisson distribution. Flight plans are filed with ARTC Centers at varying intervals prior to the departure of aircraft, although it is requested practice that they be filed not less than 30 minutes prior to departure. Since flight plans arrive at the ARTC Center at random intervals, some queueing will occur in the processing. Time measurements of the processing of data using the IBM 650 system show that an average flight plan requires an over-all handling time of approximately 4 minutes from the time the flight plan is received at the Center to the time of delivery of flight strips to the control board. If a number of flight plans are received at about the same time, the processing will begin to back up, and it becomes necessary then for the flight plans to be filed early enough to wait their turn for processing and still reach the flight progress boards in time for use by the controller.

By addition of operating personnel, the probability of delays can be reduced to a small value for all of the manual operations in the system. The limiting factor then becomes the computer processing time.

Tables VII and VIII were developed to permit a comparison of the IBM 650 system and the FLIDAP system at certain probability levels of delay, and to indicate the personnel requirements.

Several assumptions were made in these comparison charts:

1. Based on discussions with, and previous studies by, the Franklin Institute Laboratories, a Poisson distribution was assumed for the time of filing of flight plans.

2. Based on previous studies made by Bell Telephone Laboratories of service times on telephone messages, it was assumed that no large errors would be introduced by use of the same number of strips for each flight plan.

3. It was assumed that each flight-plan receiving operator could answer any call as it comes in; that is, any interphone line could be answered by any free operator.

4. One operator would be used on the IBM 533/650 unit, and one operator on the IBM 407 printer.

5. The number of runners, typists, and strip stuffers could be supplied as necessary.

A timing chart indicating the practical capacity for the IBM 650 computer system was set up as follows:

1. The basic process time. This is the length of time spent in processing a flight. This time cannot be cut down by the addition of personnel.

2. The return time. This is the length of time required for a man to return to a starting point once his duty is completed.

3. The service time. This is the total of process time and return time, and is the length of time used in the calculation of delays. Delays were determined from appropriate delay curves using service times listed below.

TABLE VII

IBM/650 COMPUTER TIMING

	Process Time (sec.)	Return Time (sec.)	Service Time (sec.)
Type	52	0	52
Run	10	10	20
Compute	10	0	10
Print	5	10	15
Edit and Stuff	90	0	90
Deliver	45	15	60
Total	212	35	247

A timing chart was constructed in a similar manner for the FLIDAP system. Assuming 3.815 strips per flight, 36 seconds to prepare a strip, and an efficiency of 90 per cent, 23.6 flights per hour can be prepared by one FLIDAP operator. This gives a process time of 152.7 seconds. Thus the timing chart becomes:

TABLE VIII

FLIDAP TIMING

Operation	Process Time (sec.)	Return Time (sec.)	Service Time (sec.)
Strip Writing	152.6	0	152.6
Delivery	45	15	60
Total	197.6	15	212.6

It is assumed that, during periods of low activity, the delivery men will stuff the strip holders. The same time has been assumed for delivery of strips from the FLIDAP and from the IBM 650 system.

The total IBM 650 process time is 212 seconds against 197.6 seconds for the FLIDAP system. In the IBM 650 computer system depicted, a practical capacity is shown. The printer requires 15 seconds, and is a one-man operation; eventually, it becomes the bottleneck in the operation, if it is assumed that only one printer is used. For example, even though the service time of the individual typists is much larger than that of the printer operator, the delays of the typists can be reduced by adding more 826 machines and more operators. This does not mean that the individual process time is reduced, but this time remains the same, namely, 52 seconds. Additional men also can be added to the FLIDAP system, as required.

In calculating the delays for systems where consecutive operations are performed, it is assumed that the bottleneck determines the maximum processing rate; that is, no delays are added to the system by any of the other operations if they can keep up with the average incoming rate. Although some lesser delays are generated ahead of the bottleneck, the rate still would be governed by the bottleneck. If the service time of the printer operation could be reduced to a value equal to or less than the computer service time, the bottleneck would be the computer, and the theoretical capacity of 396 flight plans per hour could be obtained.

As an example of the use of Table IX, let us assume an input of 100 flights per hour at a certain facility. What can be expected if a computer is installed? With 8 personnel assigned as the chart shows, 3 flights out of 100 will receive a delay of more than 2 minutes, whereas a negligible number of flights, less than 1 in 1,000, will receive a delay greater than 4 minutes. One flight in 100 would receive 162 seconds' delay, and the average delay per flight would be 30 seconds. With an increase of personnel to 14, delays will be negligible, that is, less than 1 flight in 1,000 would be delayed more than 2 minutes, 1 flight in 100 would be delayed 47 seconds, and the average delay per flight would be 5 seconds.

If this facility, with an input of 100 flights per hour, installed a FLIDAP system, using 9 personnel as shown in Table X, 15 flights out of 1,000 could expect to be delayed more than 2 minutes, and less than 1 in 1,000 would be delayed more than 4 minutes. One flight out of 100 would be delayed 150 seconds, with an average delay per flight of 15 seconds. With an increase of personnel to 12, the delay greater than 2 minutes would be negligible, with 1 flight in 100 receiving a 55-second delay, and an average delay per flight of 2 seconds.

The delays shown in Tables IX and X are in addition to the minimum processing time. The delays change as they do because men must be added as integers and not as fractions. In the IBM 650 computer system, Table IX, 50 flights per hour would require at least 2 typists and the rest of the system remains current. At 100 to 150 flights per hour, typists would be added as needed, and men would be added throughout the system to remain current. To this point, no bottlenecks are allowed after typing. With 200 to 220 flights per hour, the printer becomes a bottleneck. This cannot be broken by using more men. The average delay can be expressed by

$$\text{Delay time} = \frac{1}{2}\frac{(\text{load})}{(100 - \text{load})} \text{ X service time}$$

TABLE IX

PRACTICAL CAPACITY OF THE IBM 650 COMPUTER SYSTEM

Flights Per Hour (avg. 3.185 strips per flight)	50	100	100	150	150	200	220
Typists Required	2	2	3	3	4	4	4
Carriers and Deliverers	3	3	4	4	5	5	6
IBM 533 Operators	1	1	1	1	1	1	1
IBM 407 Operators	0	0	1	1	1	1	1
Sort-Stuff Editors	2	2	5	5	6	6	6
Total IBM Equipment Personnel	8	8	14	14	17	17	18
Probable delay greater than 2 minutes (percentage)	Negligible	3.0	Negligible	1.0	0.1	5.0	2.2
Probable delay greater than 4 minutes (percentage)	Negligible	Negligible	Negligible	Negligible	Negligible	0.5	1.0
Delay (seconds) at P = 0.01 (one out of 100 could expect this delay)	55	162	47	120	75	180	285
Average delay in excess of optimum processing (seconds)	6	30	5	20	12	37	75

TABLE X

PRACTICAL CAPACITY OF THE FLIDAP SYSTEM

Flights Per Hour (avg. 3.815 strips per flight)	Writers Required	Carriers Required	Total FLIDAP Personnel	Probable delay greater than 2 minutes (percentage)	Probable delay greater than 4 minutes (percentage)	Delay (seconds) at P = 0.01 (one out of 100 could expect this delay)	Average delay in excess of optimum processing (seconds)
50	5	3	8	Negligible	Negligible	60	2
100	6	3	9	1.5	Negligible	150	15
100	8	4	12	Negligible	Negligible	55	2
150	9	4	13	0.5	Negligible	98	8
150	10	5	15	Negligible	Negligible	61	4
200	10	5	15	4.0	0.3	178	28
220	10	6	16	2.0	0.8	222	57

For example, the eventual bottleneck in the IBM 650 computer system, which is the printer operation, has a service time of 15 seconds, service time being the total time required to process and return before starting the operation again. This means a maximum capability of 240 flights per hour. If 180 flights per hour came into the system, the load (any number of flights coming into the area per hour) on the printer would be $\frac{180}{240}$ X 100, or 75 per cent.

Inserting these data into the above equation, we have

$$\text{Delay time} = \frac{1}{2}\frac{(0.75\qquad)}{(1.00 - 0.75)} \times 15 = 22.5 \text{ seconds}$$

Thus, if 180 flights per hour enter the system, each flight can expect an average delay of 22.5 seconds.

It is evident from the above equation that delays build up rapidly as the system nears capacity. This equation applies only when the bottleneck is caused by a single unit, and not when the bottleneck is caused by several units simultaneously.

MAINTENANCE

The IBM 650 computer system was operated on an 8-hour-day basis, 5 days a week. One day each week, after the regular 8-hour operating period, IBM personnel devoted 2 hours to the computer system for preventive maintenance. Equipment failures did occur, as shown in the maintenance record, Table XI, for the IBM computer system at the Indianapolis Center for the months of September and October, 1957.

TABLE XI

MAINTENANCE RECORDS

Date	Machine Out	Time Out	Time In	Remarks	Time Off During 5-Day Week
9/4	650	0815	0945		1 : 30
9/4	3 - 826	0815	1030	Routine check while 650 out (only excess time counted)	: 45
9/5	650	0800	1400 9/30		6 : 00
9/28	650	0800	1100	Report to IBM 9/30 0915	4 : 00

TABLE XI (continued)

MAINTENANCE RECORDS

Date	Machine Out	Time Out	Time In	Remarks	Time Off During 5-Day Week
10/3	650 - 826	1000	1400 10/27		4 ÷ 00
10/25	650	1330	1000 10/28	Lost time only	
10/27	650	1300	0830	Friday afternoon and Monday morning	3 ÷ 00

Total IBM 650 outage for September and October, 1957 - 19 hours 15 minutes

The IBM computer operated from 0700 EST to 1500 EST each weekday. During the period covered by the maintenance recorded, the computer was scheduled to operate for a total of 352 hours. The percentage of computer outage was 5.46 per cent, or the IBM computer system operated at 94.54 per cent efficiency.

ACCURACY

A high degree of accuracy is extremely important in the preparation of flight progress strips. In the manual preparation of these strips, a varying amount of the controller's time must be spent in checking strips for errors such as, transposed numbers (identification, route of flight, altitude, and so forth), incorrect strip color for direction of flight, incorrect fix posting or omission, and incorrect time estimates.

The work of every assistant controller is slightly different. The controller automatically places a degree of confidence in his assistant, based largely on his previous performance. A controller's proficiency can be influenced greatly by the amount of assurance he can place on his assistant's accuracy.

When using the IBM 650 computer system, if the original input card is correct, the output will be comparatively error-free. The time estimates, fixes, route number, and so forth, need not be of particular concern to the controller. Normally, the flight plan input data are received via the schedule F teletypewriter circuit, and then are typed by an assistant controller onto an input card. If an error appears in the received flight plan, the error is carried onto the input cards, and on throughout the computer system.

During these tests, the flight progress strips were printed on strips of one color, using only black letters. The operator who sorted and stuffed strips into their holders placed a red arrow in the control warning box to denote direction of flight.

A sorting process was necessary for direct-route flight progress strips, since the computer produced a strip for each fix within 35 miles of the flight route, and all strips were not required for control purposes. The IBM 650 computer was programmed to calculate direct flights abeam fixes, with the direction from the fix printed on the strip to the nearest 8-point compass direction. Therefore, direct-flight progress strips produced by the IBM 650 computer, as programmed, had no reference to the point where the flight crossed airways. This required interpolation by the controller to determine a common point of crossing with airway traffic. The computer could be programmed to print a flight progress strip for each airway it crosses, but so many strips would be printed for multiple airways radiating from a fix that this approach was not considered practical.

To compare the accuracy of fix estimates of strips prepared by the IBM 650 with those prepared manually, a total of 1,359 flight progress strips, covering peak periods, were analyzed to indicate the number of minutes the Center's estimate differs from the aircraft's actual time over a fix.

Of 950 flight progress strips processed by the IBM 650 computer system, the original fix time estimates on 489 flight progress strips showed the original estimate with no revisions. Of these 489 reports, 375 or 76.6 per cent showed an actual position report within 3 minutes of the Center's estimate.

Of 409 flight progress strips which were prepared manually and analyzed, 248 showed the original estimate with no revisions. Of these 248 strips, 178 or 71.7 per cent showed an actual position report within 3 minutes of the Center's estimate. Based on original time estimates, the IBM-prepared flight progress strips were about 5 per cent more accurate.

LEGIBILITY

The strips produced by the IBM 650 computer were very legible and neatly printed, although the standard-size type was too small. When an entire bay of a flight progress board was filled with IBM strips, all of one color, controllers complained of an hypnotic effect. A modification to the 407 printer subsequently was ordered to use three different sizes of print wheels. In addition, Courtney and Co. made a study of the printed strips from the human-factor standpoint and made certain recommendations for improved readability. Examples of these strips are shown in Fig. 5. Samples of strips produced by the computer and used in control on September 11, 1957, are shown in Fig. 6. Two of these are of average legibility, while the remaining two show poor legibility. Figure 7 shows samples of manually prepared strips from the same day's traffic which also were judged to represent average and poor legibility.

ECONOMIC FACTORS

The IBM 650 computer and its associated parts had a rental cost of $6,165 per month based on an 8-hour day, 5 days per week. The power required for the IBM 650 computer was 220-volt, 100-ampere, three-phase, while the IBM 407 printer and the IBM 826 card punches required 110-volt, single-phase service. The IBM 650 computer system required 400 square feet of floor space. The floor must be capable of holding the following weights:

1. IBM 650 console, 1,996 pounds.
2. IBM 655 power unit, 2,972 pounds.
3. IBM 533 input/output device, 1,295 pounds.
4. IBM 407 accounting machine, 2,625 pounds.

Air conditioning is required for the computer system for operation in an ambient temperature range of 50° to 90° F. Each computer component dissipates heat at the following rate:

1. IBM 407 accounting machine, 7,500 BTU per hour.
2. IBM 650 console unit, 32,800 BTU per hour.
3. IBM 533 input/output device, 1,500 BTU per hour.
4. IBM 655 power unit, 14,000 BTU per hour.

No humidity control was necessary with the standard 650 system.

The only unexpected requirement for the computer in the Indianapolis Center was the shielding necessary because of the radar installations in this area. Wire hardware cloth screening was used on the walls of the room for this purpose.

The paper stock used for flight progress strips for the IBM 407 accounting machine costs $1.09 per 1,000 strips. The Indianapolis Center used approximately 200,000 strips per month in training and operation. The IBM cards used as input and output cards for the IBM 826 typewriter and the IBM 533 read-punch device cost $1.19 per 1,000.

It is believed that the IBM 826 operators should be trained assistants. About six weeks' training was required to be an efficient IBM 826 operator. IBM furnished schooling to the Center personnel free of charge.

OTHER FACTORS

Manually prepared strips are always subject to errors in accuracy and legibility. The controller checks and rechecks his strips constantly for such errors. The manually prepared strips possess definite recognition features. For example, every assistant controller has individual handwriting characteristics which assist the controller in picking out strips on the same flight posted under other fixes.

The strips prepared by the IBM 650 computer system provided the controller with correct initial estimates and accurately prepared fix postings.

At the time of this evaluation, the Indianapolis ARTC Center was operating with 13 sectors. Two assistant controllers were required at some of the A positions during heavy IFR traffic conditions when preparing strips manually. The average number of assistant controllers assigned on a shift was 16 The IBM computer required 18 assistant controllers to operate the system at a practical capacity of 240 flights per hour. The maximum number of flights per hour during the peak periods analyzed was 149. In addition to the assistant controllers for the IBM system, an assistant controller was re-required at each or every other sector to work with the controller. These assistant controllers prepared some strips manually for flight plans filed in flight and when approval requests were received, but the major portion of their time could be spent in aiding the controller in the control of air traffic.

CONCLUSIONS

The following conclusions were reached as a result of the evaluation of the use of the IBM 650 computer in the Indianapolis ARTC Center. These conclusions are based on the environmental conditions existing in the Indianapolis Center area and on the programming used in this machine. The original IBM 650 computer installation at this Center since has been replaced with an IBM 650 RAMAC which provides a tremendous increase in storage capacity.

1. Approximately 4 minutes were required for processing the average flight plan on the IBM 650 system from the time of receipt of the flight plan at the Center to delivery of the flight progress strips to the control boards.

2. The maximum capacity of the IBM 650 system for processing flight plans was 396 flight plans per hour, or 1,510 strips per hour. To operate at this rate would require 31 operations personnel, not including supervisors.

3. With 11 men assigned to the IBM 650 computer, as was done in the Indianapolis Center, the maximum possible processing rate was 82 flight plans per hour, or 311 flight strips. Sampling of 4 peak days showed a maximum of 64 flight plans actually processed in one hour.

4. The preparation of flight progress strips by the IBM 650 computer system and manual processing on the back side of Pittsburgh-type flight progress boards indicated that 45 to 50 strips per hour per man could be produced, whereas the simulated FLIDAP operation could produce 60 strips per man per hour.

5. The principal advantage of the computer-processed strips is the improved legibility, and the reduction in probable human errors in manual preparation of strips.

6. The strips as prepared by the standard IBM 407 accounting machine with the IBM 650 computer were unsatisfactory in that the type size was too small, and their uniform appearance tended to produce an hypnotic effect as

reported by the controllers in the Center. The use of different colors to denote direction of flight would aid the controllers. This is being incorporated in the IBM 650 RAMAC computer.

7. The IBM 650 computer system, as programmed, used virtually all of its possible 2,000 words of storage. Some flight plans could not be accepted because certain fixes were not stored in the computer. No confliction search, transmission of flight plans from Center to Center, or on-line capability, was possible.

RECOMMENDATIONS

1. It is recommended that the IBM 650 computer system as installed and programmed in the Indianapolis ARTC Center not be used in additional Centers. Since increased computer storage is required, it is recommended that only computer systems with considerably increased capacity be considered.

2. Future systems should be capable of accomplishing ATC functions such as:

a. Preparing flight progress strips.

b. Storing flight data in the computer.

c. Modifying and updating stored data.

d. Composing and transmitting data to or for an improved display.

e. Forwarding flight data intra- and inter-center, and to ADC.

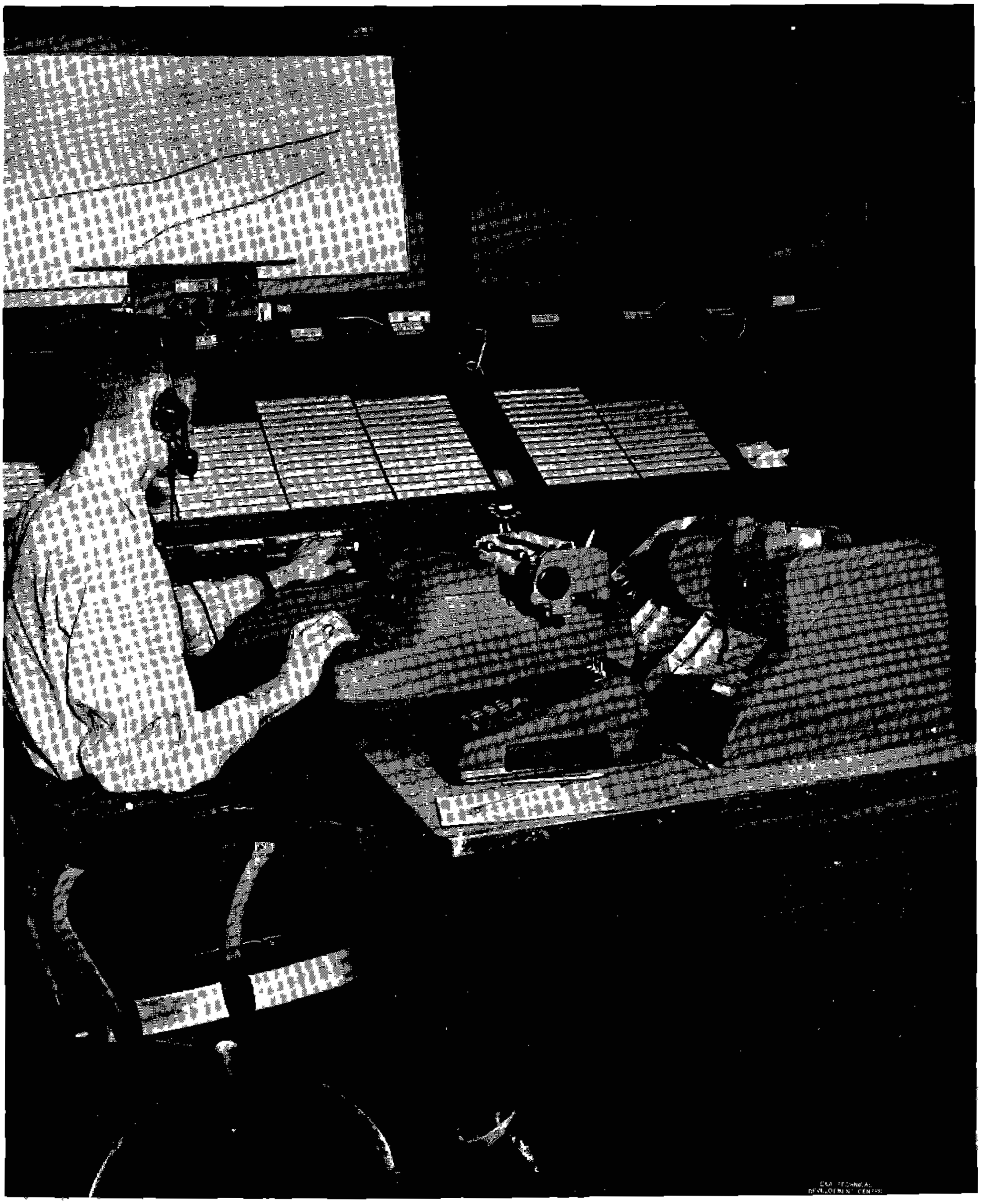
f. Providing flow control information.

g. Providing conflict detection and resolution for either controller or computer implementation.

h. Providing wind component data for more accurate time estimates.

3. Improved computer input and output equipment and techniques should continue to be investigated to provide better communications between controllers and computers, computers and display, and between computer systems.

4. It is recommended further that flight progress strips be prepared by FLIDAP operators 4 to 8 hours per day in computer-equipped facilities to retain proficiency in the event of a mechanical failure.



CAA TECHNICAL
DEVELOPMENT CENTER

FIG 1 IBM TYPE 826 TYPEWRITER CARD-PUNCH UNIT

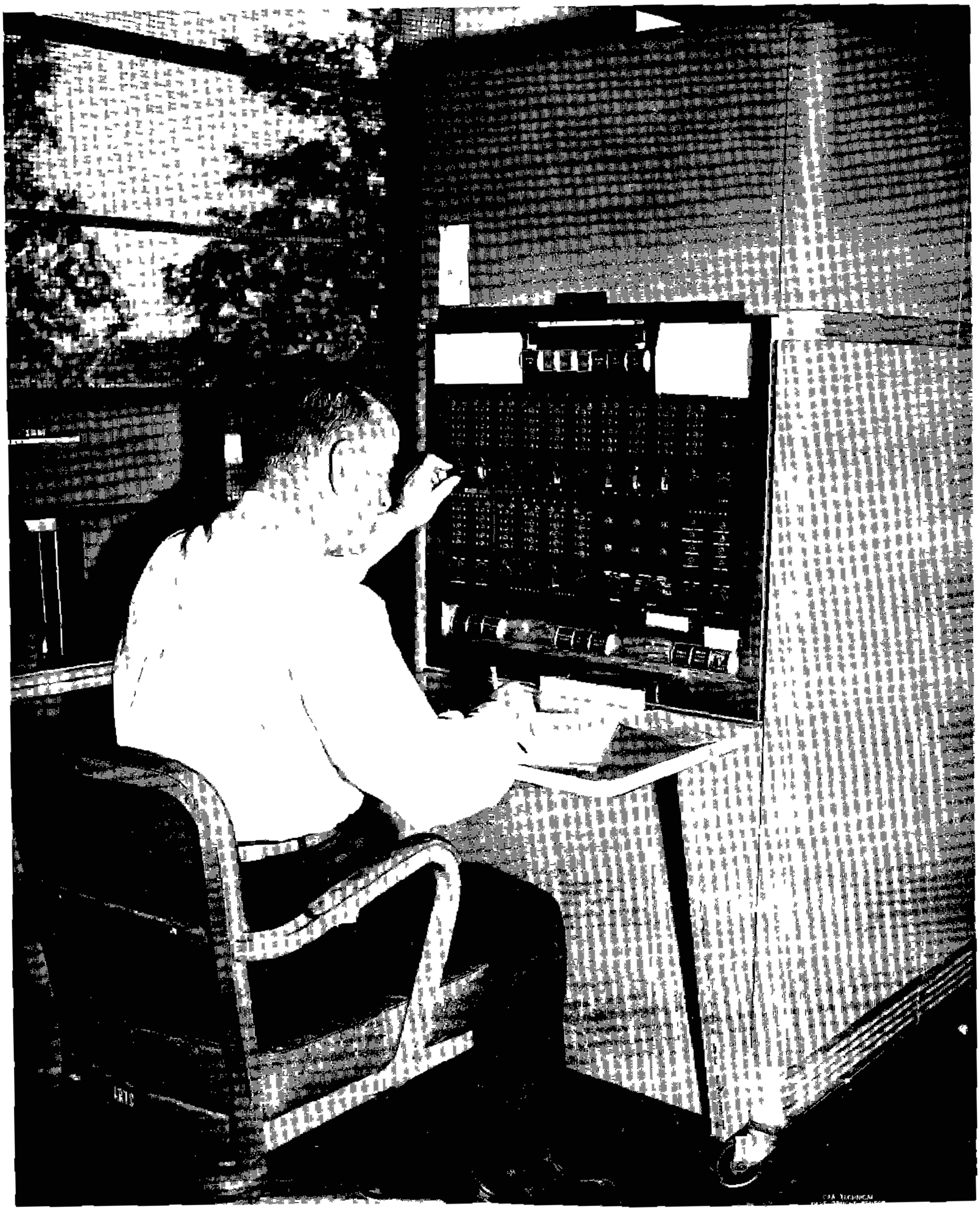


FIG 2 IBM TYPE 650 MAGNETIC DRUM DATA PROCESSING MACHINE

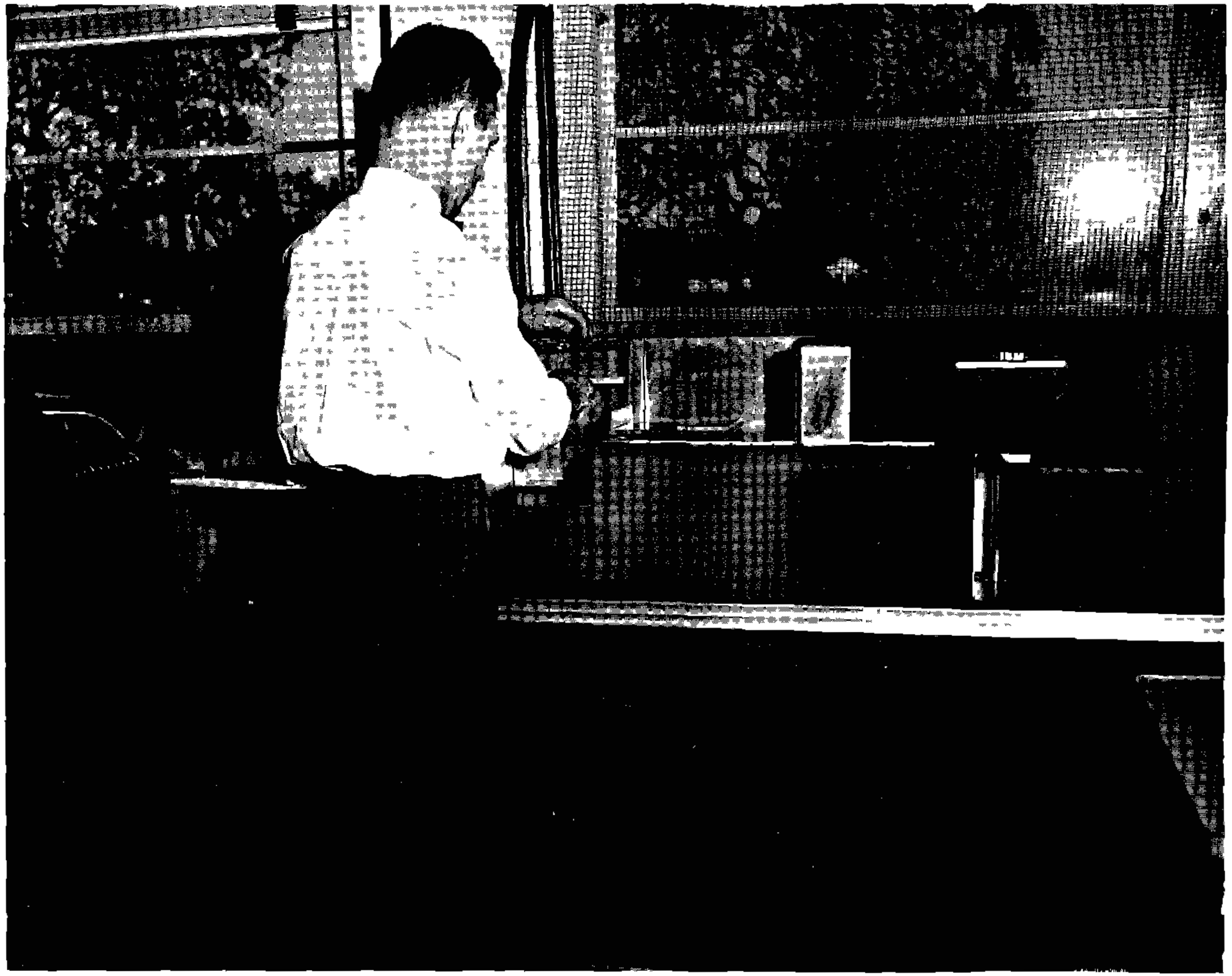


FIG. 3 IBM TYPE 533 READ-PUNCH UNIT

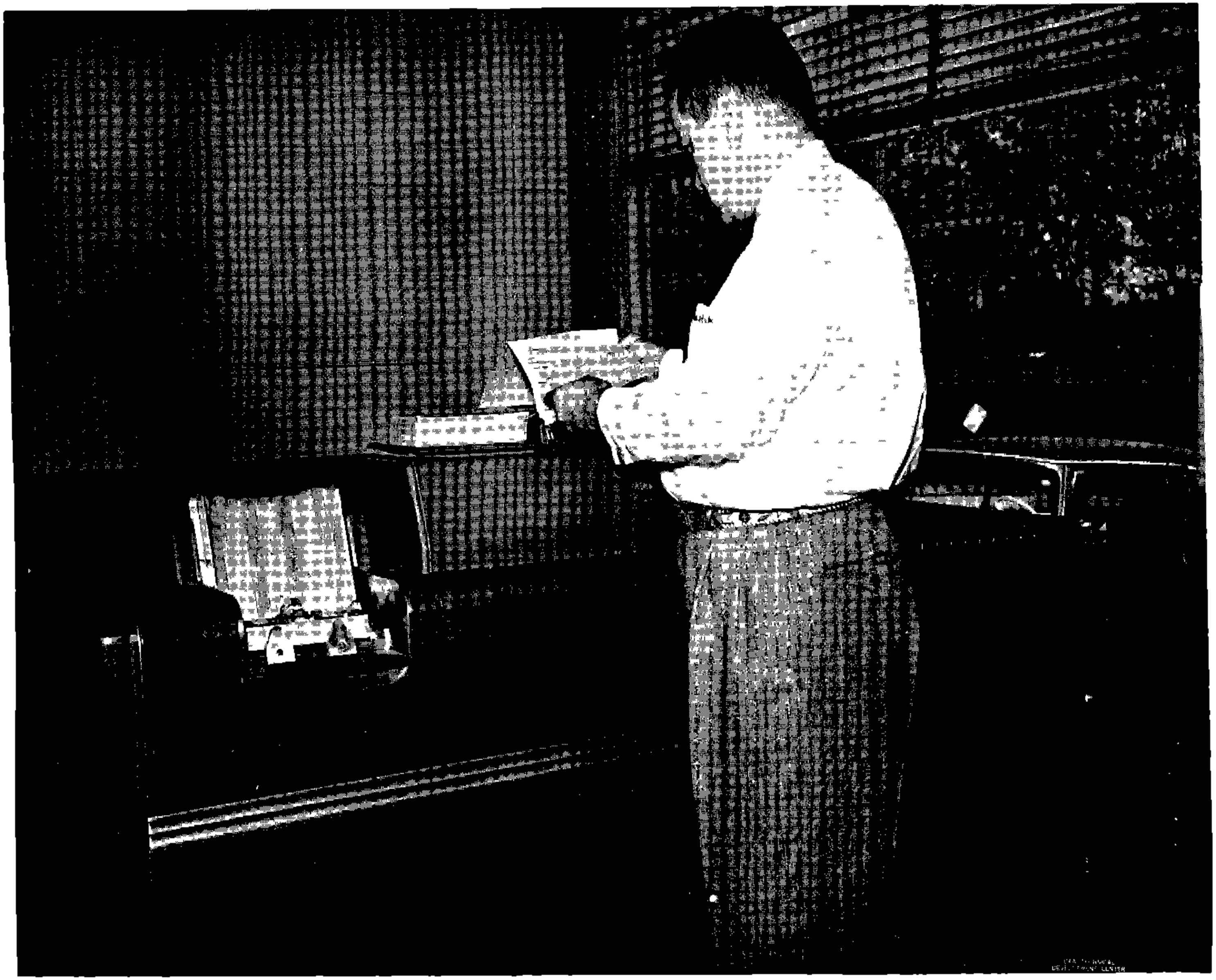
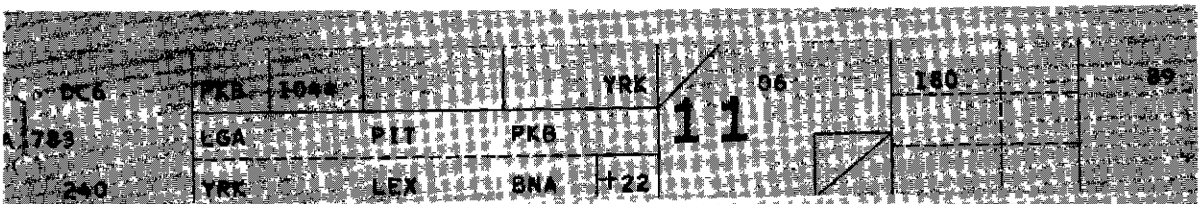


FIG 4 IBM TYPE 407 ACCOUNTING MACHINE



DC6
A 789
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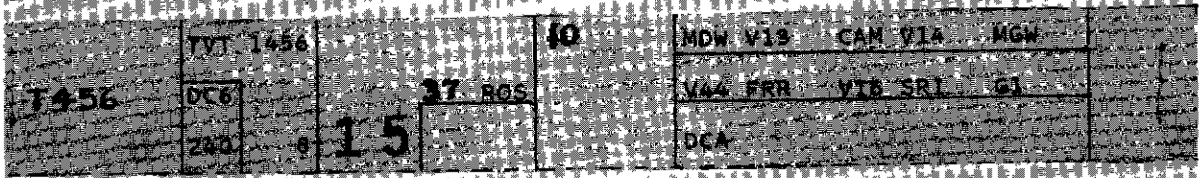
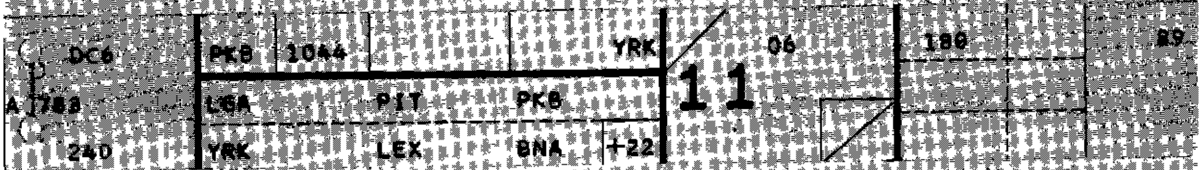
PKB 1044
YRK
LGA PIT PKB
YRK LEX BNA +22
11
06
180
89

THE PRESENT IBM 650 COMPUTER STRIP



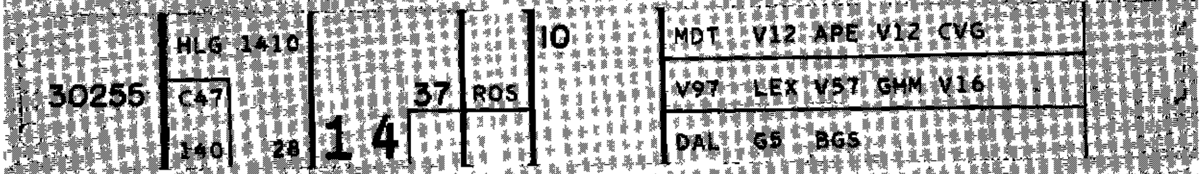
T456
TVT 1456
DC6
240
8
15
37 ROS
10
MDW V19 CAM V14 MGW
V44 FRR V16 SRI G1
DCA

THE PROPOSED IBM 650 COMPUTER STRIP



DC6
A 788
240
PKB 1044
YRK
LGA PIT PKB
YRK LEX BNA +22
11
06
180
89

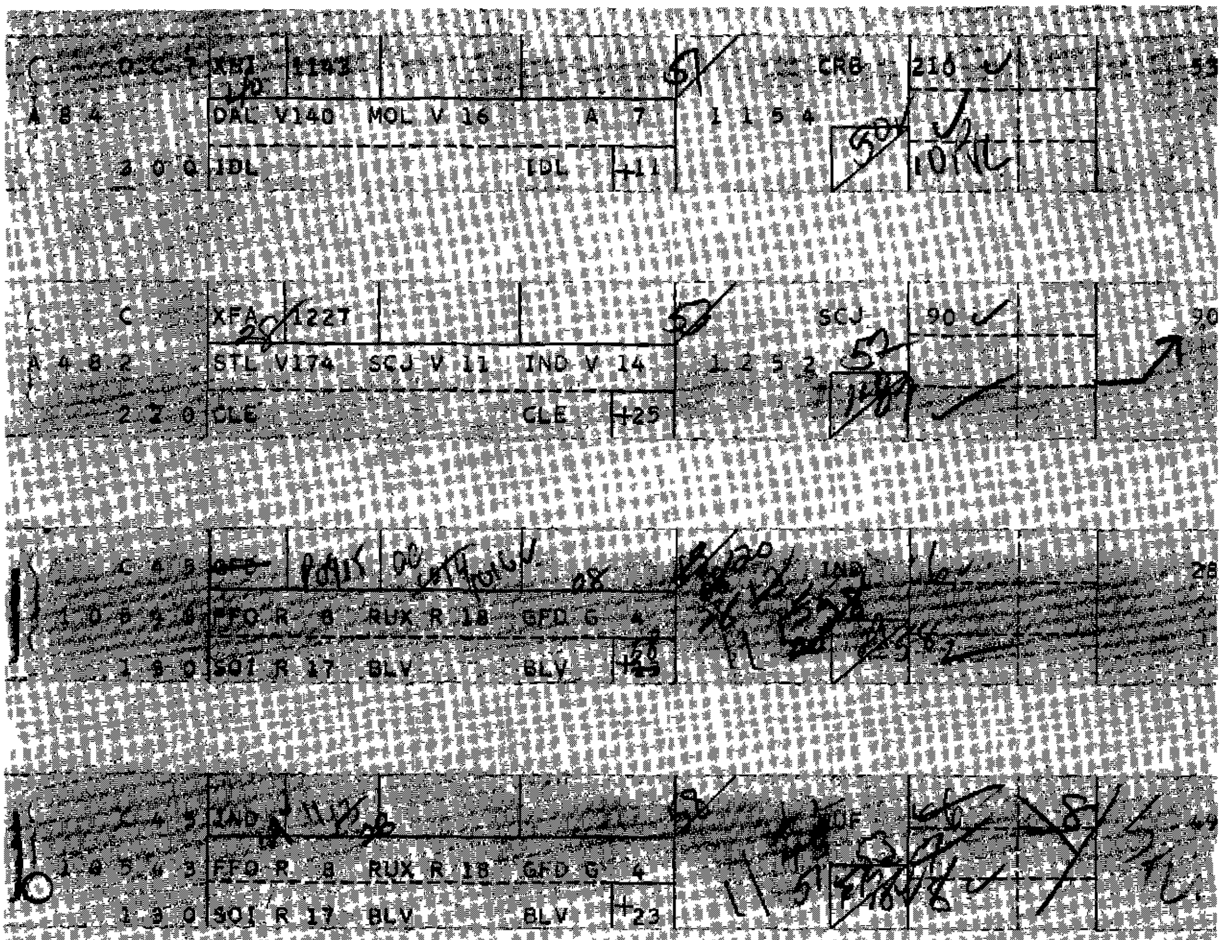
THE PROPOSED IBM 650 COMPUTER STRIP WITH THE DIVISION SCAN LINES AS RECOMMENDED BY COURTNEY AND CO.



30255
HLG 1410
C47
140
28
14
37 ROS
10
MDT V12 APE V12 CVG
V97 LEX V57 GHM V16
DAL G5 BGS

THE PRESENT IBM 650 COMPUTER STRIP WITH THE DIVISION SCAN LINES AS RECOMMENDED BY COURTNEY AND CO.

FIG. 5 FLIGHT PROGRESS STRIPS (IBM 407)



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A 8 4 DAL V140 MOL V 16 A 7 1 1 5 4
2 0 0 IDL IDL +11

C XFA 1227 SCJ 90 90
A 4 0 2 STL V174 SCJ V 11 IND V 14 1 2 5 2
2 2 0 CLE CLE +25

C 4 5 IND 28
1 0 5 4 3 FFO R 8 RUX R 18 GFD G 4
1 9 0 SOI R 17 BLV BLV +23

4 5 IND 44
1 0 5 4 3 FFO R 8 RUX R 18 GFD G 4
1 9 0 SOI R 17 BLV BLV +23

FIG. 6 EXAMPLE OF FLIGHT PROGRESS STRIPS (IBM 650)

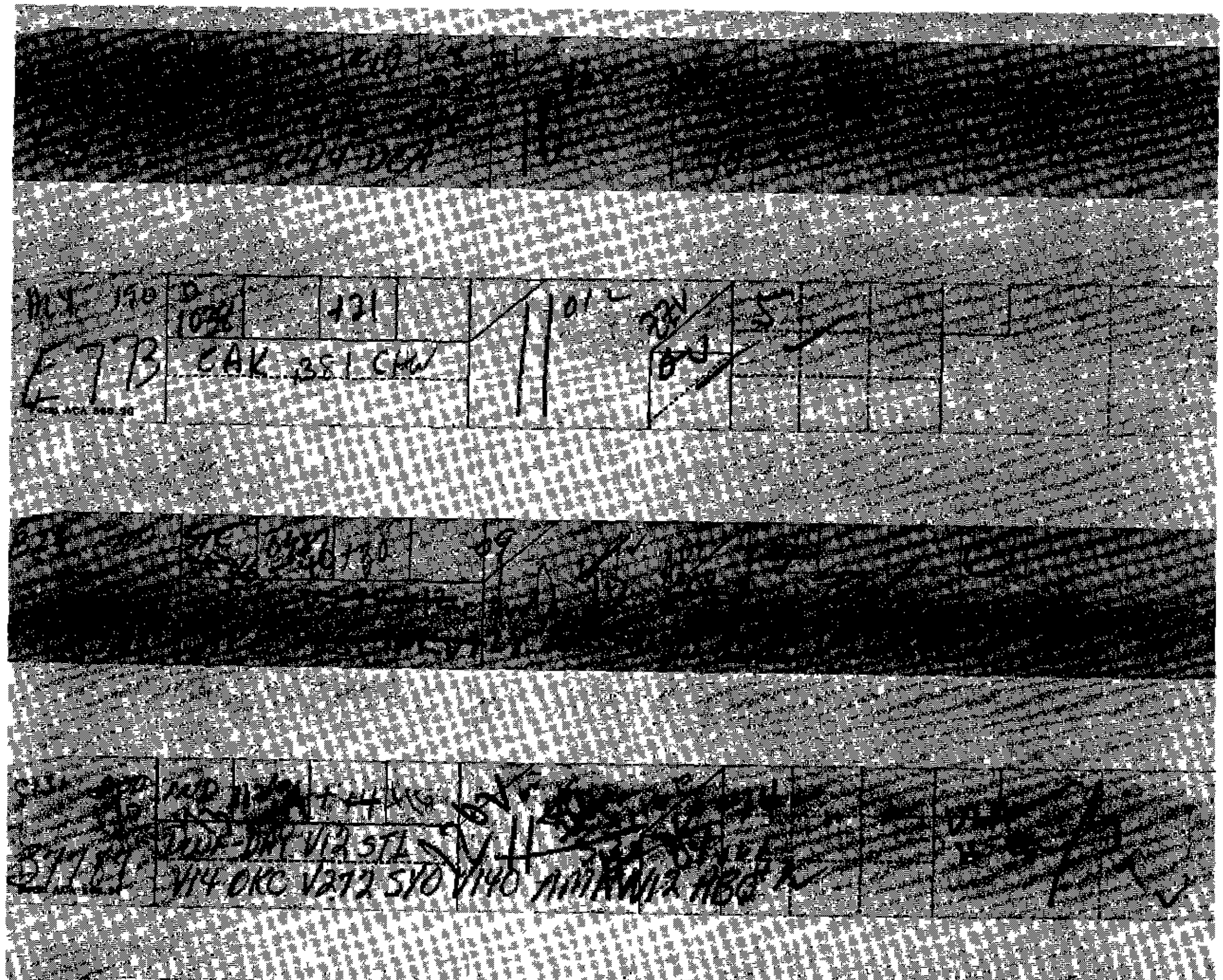

FIG. 7 EXAMPLE OF FLIGHT PROGRESS STRIPS PREPARED MANUALLY