Institute of Space and Aeronautical Science University of Tokyo
Report No. 398, October 1965

Air Traffic Control Automation in Japan

By

Minoru OKADA, Jun TAMIYA
and Masutoshi ITO

Summary. To maintain safe and efficient Air Traffic Control Service coping with ever increasing air traffic, ATC automation is of importance in the ATC system modernization. This paper describes the basic studies and developments for the ATC automation system that will be implemented at the Tokyo Area Control Center with its initial operation in 1968.
Based on the system design philosophy obtained from our study, a real-time computer data processing system has been adopted from the first phase of this automation. Particular emphasis has been placed on the system-reliability and the man-machine interface, both having been recognized as the most important factors in such a real-time system. Also the simulation study with actual traffic data has been carried out for evaluating system operations.

1. INTRODUCTION

The Tokyo Area Control Center having Tokyo, the heart of very rapidly developing Japanese domestic air traffic, is the biggest and the most important Air Traffic Control Center in the Tokyo Flight Information Region. The Tokyo FIR to which the Tokyo ACC is responsible covers the Japanese islands and the Western Pacific which extends from 125°E to 165°E and from 25°N to 51°N. And the traffic within this area increases at an yearly rate of 11%. In order to maintain safe and efficient Air Traffic Control Service coping with ever increasing traffic both in numbers and velocity, the Japanese Government decided to implement ATC Automation in the Tokyo ACC expecting its initial operation early in 1968. This plan was started originally in 1962, and completed the basic development phase which included simulation studies with actual traffic data. System evaluation and equipment production are now in progress. The plan when it was formulated, much attention has been paid to the Japanese traffic characteristics. Evolutional improvement of present manual procedures and flexibility for future expansions are incorporated. A real-time system with key-packs and displays has been adopted on the ground of our firm belief that not only flight plan processing and flight progress strip printing at each controller console but also updating and conflict search functions are mandatory for our traffic control system. Particular emphasis has been placed onto the design of the man-machine interface which has been recognized as one of the most important items in a real time system. Efforts have been made to realize a highly reliable system adopting the Fail/Soft concept in case of equipment malfunctions.

2. Basic Philosophy of ATC System Design

Analysis of present traffic control procedures and traffic statistics were made prior to the system design planning. Also, future ATC procedures have been studied taking present and future subsystems into consideration. Finally, the system design has been initiated based upon the following philosophy.

(a) Free route system/Fixed route system

The free route system offers the maximum utilization of the available airspace. Therefore, this concept has been adopted for the oceanic control area and high altitude control area. However, the fixed route concept has been left for the domestic low altitude control area, due to topography of the Japanese islands, distribution of navaids and nature of traffic.

(b) Continuation of flight progress strip procedures

Electro-mechanical display or electronic display have been introduced in certain countries as successors to the present manual flight progress strip display. But we have decided to use flight progress strips for the initial stage of Automation. Our careful examination of the present strip display revealed:

(1) It displays the traffic pattern very clearly and precisely.
(2) Updating is easily done by the controller, and this manual updating helps the controller to confirm the traffic he is controlling.
(3) It would serve as the most effective means should it become necessary to revert to manual in the event of the computer failure.

The most obvious difficulty associated with the strip display is its double updating by the controller, the one to the computer and the other to the strip. A complicated mechanism will enable the double updating by single action, however, we did not adopt this complicated mechanism because of reliability and the followings:

(1) Increase of the computer updating by key operation can well compensated with decrease of the controller workload due to the computer assistance.
(2) Time search function of the computer always advises the controller whether or not he has forgotten some updating both to the computer and to the strip.

(c) Automatic conflict search

Normally, pre-flight flight plan processing is considered as the first step of ATC Automation. However, severe and sudden change of weather on account of topography, high traffic concentration on trunk airways, and mixture of oceanic and domestic flight in the vicinity of the major terminals make pre-flight processing insufficient. Updating, automatic conflict search and response to the controller's query for resolution were considered necessary from the first stage of our Automation.

(d) Automation progress step

On the ground of the aforementioned basic philosophy, our ATC Automation shall be implemented according to the following three phases:

Phase I ... Flight plan processing, Flight progress strip print out at each controller console, Updating by position reports, Conflict search, and Query/Answer.

Phase II ... Radar updating (Use of electronic tagging under consideration), Terminal Automation.

Phase III ... Overall integrated system.

The phase one system has been designed with much redundancy and flexibility for future expansions and modifications.

3. Actual System Layout

3-1. General Requirements

This system processes basic input (flight plans) sent by teletype circuits and operational input by the controller's key operation, prints out flight progress strips, answers to the queries by the controller, and displays advisory data to the controller. The system shall meet the following requirements.

(a) Operation capability
  (1) Operates 24 hours a day.
  (2) Handles 2,000 aircraft a day and 200 aircraft on-time.
  (3) Processes 40 flight plans per 15 minutes.
  (4) Processes 300 updating and queries (about 30 kinds) per 15 minutes.

(b) Operation mode
  (1) Accepts and records flight plans, and prints out flight progress strips when required.
  (2) Upon accepting an updating message executes conflict search, updates files and displays updating and conflict information to the controller console.
  (3) Answers to the controller's query about any proposed clearance change.
  (4) Records all input and output for the legal purposes.
  (5) Processes data for statistics.

(c) Fail/Soft
  (1) Dual computer system shall be used.
  (2) Emergency backup power supply system shall be equipped.

(d) Future expandability
  (1) The system shall provide for easy connection with other ATC automation systems.
  (2) The system shall have flexibility for future expansions.

3-2. *Computer system*

Figure 1 shows the system block diagram. Dual computer system has been adopted for higher reliability which is required for real time systems as the most important prerequisite. The two computers do the same processing and check each other during and at the end of the processing. The magnetic drum shall be used for storing files of all traffic in the system, tables of airways and routes, airports, and aircraft, weather data and others.

Magnetic tapes shall be used for storing legal records and data for emergency purpose. Also statistics data processing and program updating can be done using the tapes.

Table 1 shows the computer and peripheral equipment performance characteristics.

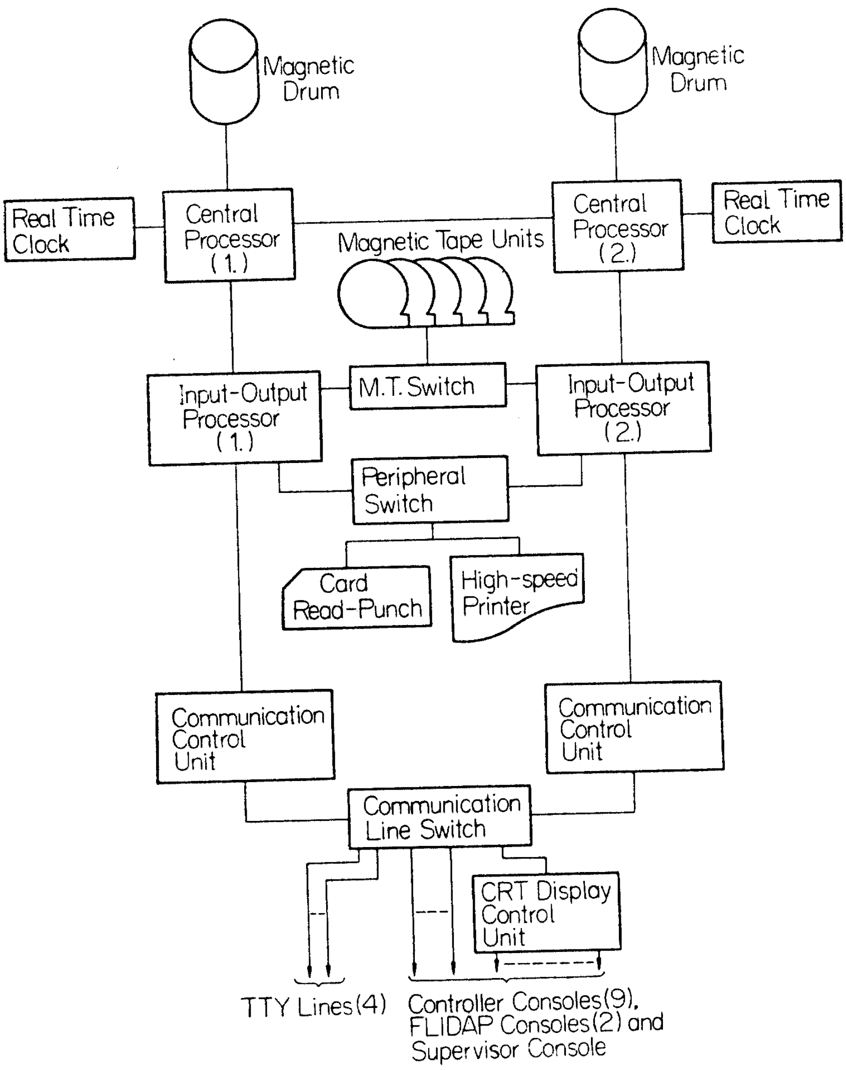

Figure 1. Computer system block diagram.

TABLE 1. Computer Performance Characteristics

Central Processor	45,000 instructions/sec 163 K Ch. (cycle time 1 μs)
Input-Output Processor	23,000 instructions/sec 20 K Ch. (cycle time 2 μs)
Magnetic Drum	2,621 K Ch. (av. access time 25 ms.)
Magnetic Tape	44 KC.
Communication Control Unit	64 Channel 50—2400 Baud
Card Read Punch	Read 800 CPM Punch 100 CPM
High Speed Printer	750 LPM

3-3. Man-machine interface

The computers are connected to the controller console as shown in Fig. 2 (total of 12 consoles; one supervisor console, 9 controller consoles and 2 FLIDAP consoles). Information exchange between the computer and the controller is carried out by the following subsystems of the console.

(a) Keypack

Two keypacks as shown in Figure 2 and 3 are equipped at each controller console. Tri-purpose key system is employed for the controller's convenience. The controller uses the keypack for computer updating. The followings are ass'gned to each tri-purpose key.

Primary Fix name	JE, KMA, etc
Numeral	0–9
Function	U (update), Q (query), T (Time), D (distance), ATO, TFR, HLD, ATD, ERS, ETA, CXH, ACK, ALT, VMC.

Up to 8 secondary fix keys can be placed beside the tri-purpose keys. In case of non-predesignated fixes, a special key (hatched key in Fig. 3) shall be depressed prior to inserting numerals such as rho-theta or coordinates. Key input shall be displayed on the CRT immediately for visual check by the controller, then when the execute key is depressed by the controller, it is sent to the computer.

(b) CRT Display . . . See Figure 4.

This is a dot scan type alphanumeric CRT display. CRT is used for:

(1) Visual confirmation of keypack input,
(2) Computer output display,
(3) Warning display,
(4) Response display for the controller's query.

This CRT display is an excellent data display with high speed and flexibility, and is noiseless. In fact, this CRT can be regarded as one of the superior characteristics of the system. Thirty-two alphanumeric characters can be shown on a line, and twelve lines make a total of 384 characters on the scope.

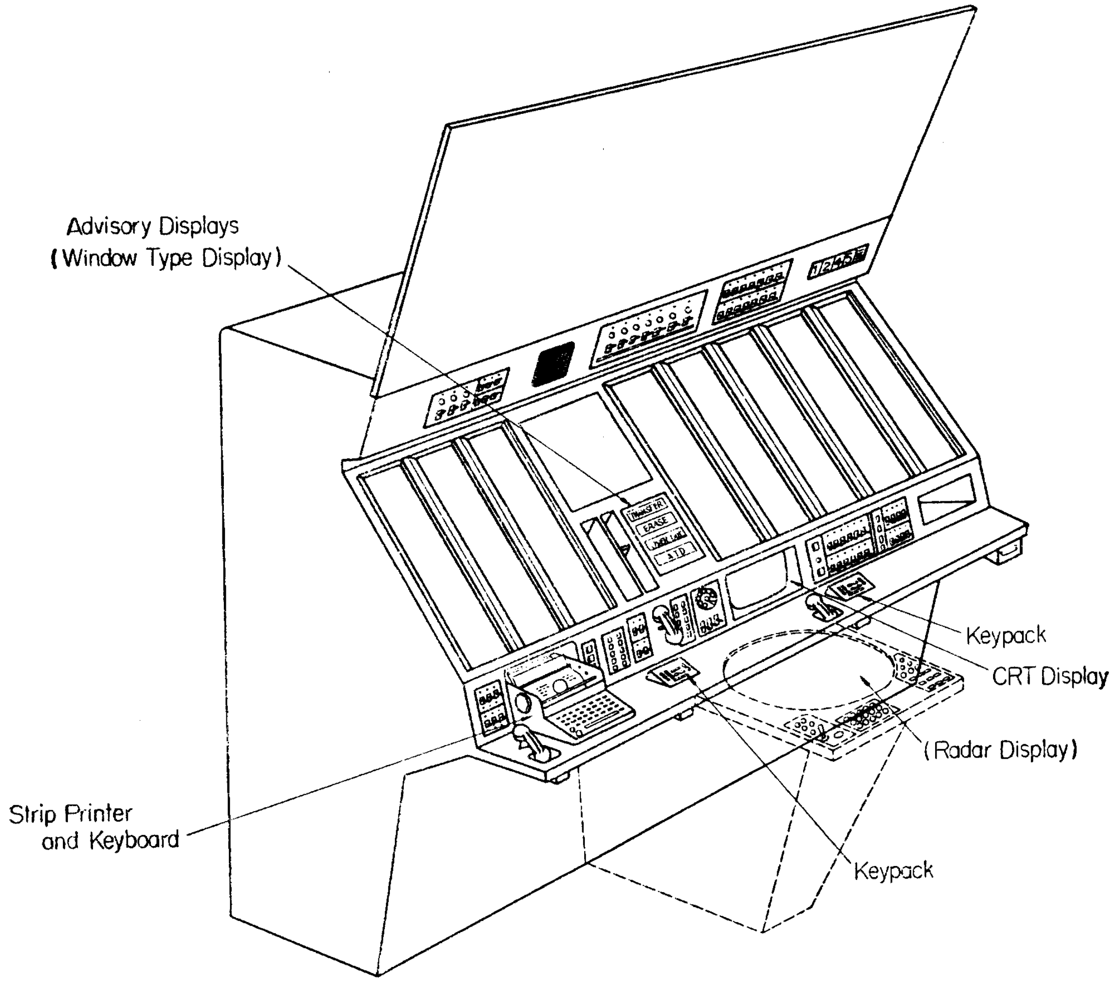

Figure 2. Controller console.

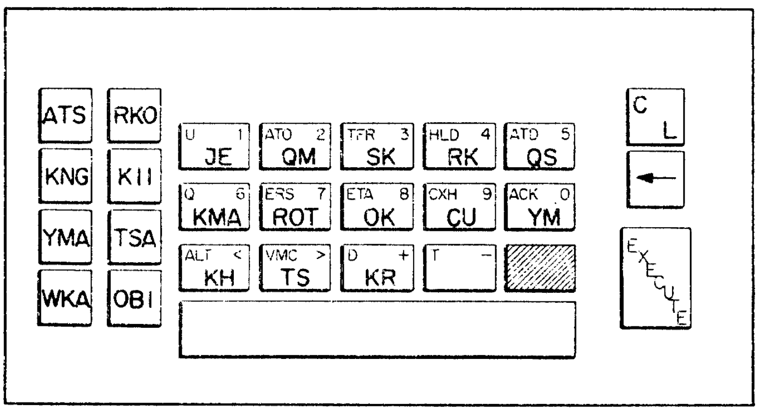

Figure 3. Keypack.

(c) Advisory displays

Window type indicators are used for this purpose. (See 4-3.)

(d) Strip printer and keyboard

A modified IBM selectric typewriter is used as a strip printer at each con-

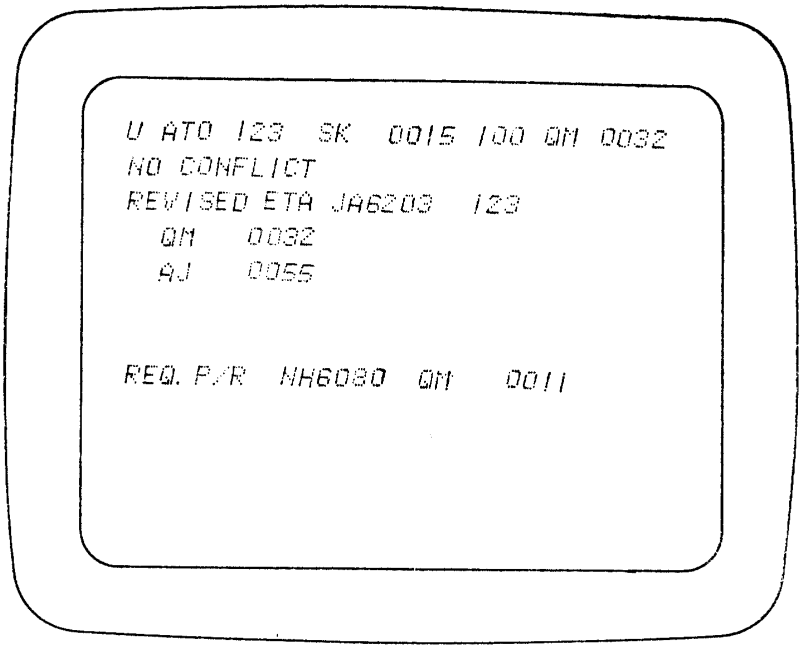

Figure 4. CRT display.

troller console. Strips for that sector are printed by this printer and various inputs can be transmitted to the computer through the keyboard.

Teletype circuits are connected directly to the system, and flight plans shall be format and validity checked before being stored to the file. Data link between the adjacent ACCs/ Terminals and addition of radar data processors are expected in near future.

4. System Operation

4-1. Basic input

Flight plans sent by teletype circuits are called basic input. Basic input shall be processed and stored within 30 seconds with format and validity checks. The following items shall be stored:

(1) type of flight, (2) identification, (3) type of aircraft, (4) airspeed, (5) departure airport, (6) altitude or flight level, (7) route of flight, (8) destination airport, (9) ETD, (10) ETE, (11) fuel, (12) alternate airport, (13) transponder code and radio frequencies, (14) personnel on board.

The following routes of flight shall be accepted by the system:

(1) airway, (2) fix-fix, (3) relative distance and bearing from fix to the same, (4) rho-theta to rho-theta, (5) coordinates to coordinates, (6) combination of the above.

Validity check shall be made for the following items and those which are found with errors and irregularities shall be displayed at the FLIDAP consoles with remarks indicating erroneous portions:

(1) Air speed and altitude/flight level correspond to the aircraft type,

(2) Route of flight is continuous,
(3) Comparison of ETD and the real time (stale flight plan),
(4) Duplication with the previous filed plans.

4-2. *Strip printing*

A departure strip shall be printed out at the appropriate sector console 30 minutes prior to ETD.

(Simultaneous printing of strips at all sector consoles is possible.)

Table 2 shows a departure strip content.

When ATD is input, original strips are printed out at sectors concerned. In case of route changes, revised strips shall be printed out likewise. Table 2 shows an original/revised strip content. Figure 5 shows an example of a printed strip. Strip color is pale green, and alphanumeric characters are red for the flights 0 to 179 degrees bound, and black for the flights 180 to 359 degrees bound.

TABLE 2. Strip contents.

	Departure strip		Original/revised strip
1.	Call sign (up to 7 ch. A/N)	1.	Same as departure strips.
2.	Computer sequential number (3 ch. N)	2.	〃
3.	———	3.	Previous fix and its ETA (fix: up to 3 ch. A; ETA: 4 ch. N)
4.	Aircraft type (up to 6 ch. A/N)	4.	same as departure strips.
5.	True Airspeed (3 ch. N.) (Mach no. can be accepted)	5.	〃
6.	ETD (4 ch. N)	6.	〃
7.	Departure airport (4 ch. A)	7.	Fix (up to 3 ch. A)
8.	———	8.	ETA (4 ch. N)
9.	———	9.	(to be filled manually)
10.	Altitude/flight level (3 ch. N)	10.	Same as departure strip
11.	Route (departure and destination airport: 4 ch. A; fix and route: up to 4 ch. A/N)	11.	〃
12.	Printout time (6 ch. N)	12.	〃

A: Alphabetical, N: Numeric, A/N: Alphanumeric.

JA6203 123	XM 2358 DC6 245	15 00	SK	100	RJTT DCT PQ G4 FK DCT RJFF	032315

Figure 5. A printed flight progress strip.

4-3. Real time operation...computer updating, query, etc.

Input from the keypack by the controller and from the keyboard by the assistant are called operational input. These input and output devices such as keypacks, a CRT, advisory displays and a typewriter enable real time operation by the controller. The controller updates the strip and operates the keypack when he receives a position report. Then he has to confirm accuracy of his keypack operation by visually checking the CRT. With his depression of the execute key the computer updates the file and executes the conflict search routine. When a conflict is detected, a warning message shall be given to the controller on the CRT. The controller may query to the computer using the keypack whether or not his revised clearance would cause another conflict situation. When issued a revised clearance he has to update the computer. Then all the sectors concerned is advised the change by their CRTs. The controller also may request any information about his traffic using his keypack, and its answer shall be displayed on the CRT.

Examples of updating messages:

Position Report ... U ATO 123 SK 0015 100 QM 0032
(underlined characters displayed automatically by the computer)

Query ... Q ALT 123 QM 140

Altitude change ... U ALT 123 QM 140

Handoff ... Intersector handoff is automatically done by position report input

Release to terminal ... U TFR 123

In order to carry out the above mentioned functions smoothly and efficiently,

Altitude	No. of A/C in this alt.				File for one altitude
A/C seq. No.	A/C type	Air-speed	Status code		Aircraft
Sector No.	Fix No.	ETA/ATO	Fix type code	←First fix	
Sector No.	Fix No.	ETA/ATO	Fix type code	←Second fix	
⋮	⋮	⋮	⋮		
A/C seq. No.	A/C type	Air-speed	Status code		
Sector No.	Fix No.	ETA/ATO	Fix type code		
⋮	⋮	⋮	⋮		
Altitude	No. of A/C in this alt.				
⋮	⋮		⋮		

Figure 6. ALAFE File.

a special file called ALAFE File (Altitude, Aircraft, Fix, and ETA File) was developed for this system, as shown in Figure 6.

The computer assigned sequential number is used for computer-controller communication in lieu of the aircraft identification. Easiness of handling the sequential number was proved during the evaluation tests. The following advisory displays (window type indicators) are located on the controller console;

(1) Request ATD ... when there is no ATD input 15 minutes past clearance issuance,
(2) Request P/R ... when there is no position report 5 minutes past the latest ETA,
(3) Request Transfer ... 15 minutes prior to the release point ETA (60 minutes in case of oceanic flights),
(4) Request Erase ... when no erase input is made 30 minutes past the last fix ETA.

Information request and in-flight flight plan filing can be input by the typewriter keyboard.

4-4. Supplementary Information

Wind direction and velocity, area or altitude block, navaid outage and other informations shall be input from the FLIDAP console. Change, addition and revision of the tables and programs shall be effected by the card reader.

5. Evaluation

Extensive evaluation tests of the prototype equipment are underway at present. The followings are the main features of the evaluation tests,

(1) Hard-ware operation,
(2) Program tests,
(3) Measurement of each operation time,
(4) Controller's workload.

In addition to the above, controller's technical and general comments were analized to be reflected to the production equipment.

As shown in Table 3, the controller has to spend 443 seconds/hour for the computer communication using the keypack, however, he can save the coordination communication by 703 seconds/hour as given in Table 4. Data of these tables were taken from a simulation test using actual traffic data. In addition to this decrease of controller's workload, modification and refinement of control procedures, reorganization of the controlled airspace and such would relieve the controller very much. This fact encourages the use of the keypack though it surely needs some efforts of the controller. What would happen if we are to cope with the ever increasing traffic by adding more and more sectors to our Center? Coordination and communication between controllers would deteriorate their efficiency. And, as we all know, these coordination and communication are must for the Air Traffic Control. Only automation and radar, we believe, would promise us safe and efficient Air Traffic Control Service.

TABLE 3. Keypack Operation Time

Message	No. of stroke	Time/MSG (sec)	No. of MSG/Sector/hr	Total time (sec/hr)
U-ALT	11	14	5.5	77.0
U-HLD	7	13	0.4	5.2
U-ATO	9	14	25.8	361.2
U-ATD	7	12	12.7	152.4*
U-TFR	5	8	11.8	94.4*
			TOTAL	443.4*

* Note: U-ATD and U-TFR can be handled by the assistant, making the total key operation time 443.4 sec/hr for the controller.

TABLE 4. Communication time of manual coordination saved by Automation

Message	Time/MSG (sec)	No. of MSG/Sector/hr	Total time (sec/hr)
ATO*	14.0	12.7	177.8
Revised ETA	14.0	1.1	15.4
AMIS	18.0	2.8	50.4
ATD	12.0	12.7	152.4
TFR	26.0	11.8	306.8
		TOTAL	702.8

* Note: Pass ATO to other sector.

6. ACKNOWLEDGEMENT

Development of this ATC Automation System is being conducted by the joint effort of the Japan Civil Aviation Bureau, Ministry of Transportation, and the ATC Automation Panel of Japan under the direction of one of the authors, M. Okada. The authors express their sincere gratitude and appreciation to the staffs of Japan Civil Aviation Bureau who have supported this work with deep understanding. Appreciation is also due to Professor M. Hosaka in our institute for his kind advices concerning the computer data processing. Finally, we wish to express our hearty thanks to those gentlemen, too, who have worked with us as members of the Working Group of the panel, whose names are listed below.

List of ATC Automation Working Group.

University of Tokyo

Dr. M. Okada	Professor, Institute of Space and Aeronautical Science
Dr. J. Tamiya	Professor, Institute of Space and Aeronautical Science

Mr. M. Ito	Institute of Space and Aeronautical Science.

Civil Aviation Bureau, Ministry of Transportation

Mr. S. Osawa	Deputy Director for Engineering (Retired)
Mr. N. Matsumoto	Deputy Director for Engineering
Mr. S. Izumi	Chief, Air Traffic Control Section
Mr. T. Muto	Air Traffic Control Section
Mr. T. Koichibara	Chief, Radio Engineering Section
Mr. F. Kitazawa	Radio Engineering Section
Mr. J. Yamane	Chief, Communication Section

Tokyo Area Control Center, Ministry of Transportation

Mr. Y. Kawakami	Director
Mr. H. Shimizu	Chief Controller
Mr. N. Nakata	Controller
Mr. T. Tanabe	Controller

Nippon Electric Company

Dr. Y. Ishii
Mr. K. Nakamura

Tokyo Shibaura Electric Company

Mr. T. Omagari

Mitsubishi Electric Works Company

Mr. R. Kono

Department of Instruments and Electronics
Institute of Space and Aeronautical Science
University of Tokyo, Tokyo
August 26, 1965