

THE CHARM SYSTEM
OPERATION AND RESULTS

by

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1 INTRODUCTION

CHARM was an experimental vehicle designed to study the problems of air traffic control/air defense integration. It was an early, if not the first, application of high-speed data processing techniques, such as those developed in the SAGE air defense system, to the en route air traffic control problem.

This document presents an over-all review of the results of operating the CHARM System from December 1958 through May 1959. Significant statistical data was not gathered: the Whirlwind I computer was shut down prior to the start of a comprehensive test series designed to gather quantitative data, and most of the normal periods of system operation were devoted to demonstrations of CHARM to representatives of government agencies and industry. The necessarily different mode of operation required for demonstrations made it impossible to collect detailed or useful data. However, qualitative results are presented and evaluated in terms of CHARM design objectives.

The system design is discussed in SR-4, "The CHARM System Design," by D. R. Israel et al, 4 May 1959, and is not repeated here. Notes on its implementation are contained in 6M-5989, "CHARM Design and Implementation Effort," by D. R. Israel and J. W. Quigley, 22 December 1958.

1.1 Objectives

CHARM was designed and operated with three major objectives in mind:

- a. To demonstrate potential SAGE assistance to the high-altitude, en-route portions of the present air traffic control system;
- b. To experiment with the correlation of radar data with flight plan information;
- c. To evaluate and obtain experience in using two new techniques and equipments: on-line teletype input and output, and a remote display console. Neither had been used before in SAGE.

In line with these goals, CHARM was based on SAGE, and SAGE-like techniques were used in the computer programs. CHARM was not designed to control traffic, but rather to demonstrate how SAGE might assist the controllers by displaying at an Air Route Traffic Control Center (ARTCC), remote from SAGE, an "air situation" based on flight plan and radar data. Accuracy of radar data was not a major question, as it would be in an automatic tracking program. Of first importance was ascertaining the usefulness of flight plan information in conjunction with radar data in determining the position of an aircraft. Radar data was used primarily to supplement flight plan data on direct or airway portions of the flights and as the only means of locating aircraft on radius or warning area flights. Major factors in successful correlation included the pilot's ability to specify and accurately adhere to a flight plan, and the time delays experienced between the receipt and insertion into the computer of flight plan data.

1.2 Evaluation

In Section 3, CHARM's operating results are discussed and evaluated in terms of the above objectives. Problems uncovered during operation have been published elsewhere as part of CHARM design notes and are only summarized in the results. Limited quantitative results are presented in Section 4.

2 OPERATION

The CHARM System was operated with live radar and flight plan inputs from 17 December 1958 to 23 May 1959. Operations, tests and demonstrations, were conducted twice weekly for periods of approximately three hours. During March, the system was shut down for program modification and checkout.

2.1 High Altitude Traffic

High altitude traffic monitored by CHARM consisted primarily of SAC aircraft on training flights. Smaller numbers of Navy, Air Force other than SAC, Air National Guard, and civil jet aircraft were also involved. All such high altitude traffic--24,000 feet and above--over the Boston ARTCC area was controlled from a separate High Altitude Sector in the center.

High altitude flight activity consisted of airway, direct, radius, and warning area flights, with the radius and warning area types being the most common. During the period when CHARM tests were held, there was a noticeable trend away from filing airway or direct flight plans and toward filing a radius flight with a VFR on-top clearance. (For this type of clearance, which permits the pilot considerable freedom of flight path, the controller assumes less responsibility than when he issues an IFR clearance. Consequently, the controller's knowledge of an aircraft's position is much less detailed than the case of an IFR flight plan.) This trend was a factor in the change of CHARM operating procedures discussed in Sections 2.2 and 2.3.

2.2 ARTCC Operations

During initial tests, flight plan data was fed into the computer (at the Barta Building) by direct on-line teletype from the Boston ARTCC Center. Personnel--not the actual control personnel--collected flight plan data (new flight plans, position reports, and flight plan revisions) from the High Altitude Sector and occasionally from the oceanic

sectors. The data was entered on forms having the CHARM teletype entry message sequence.* These forms were given to MITRE personnel who screened the data for timeliness, usefulness, format, and consistency with CHARM program and data storage. The data was then entered on teletype, generally by MITRE personnel at the ARTCC. The forms were then returned to the ARTCC personnel for notation of subsequent progress reports.

These procedures were not successful. Perhaps the greatest cause of difficulty was the excessive time delay due to manual handling before data was actually entered on teletype. Furthermore, sorting flight plan forms into those requiring computer entry, those requiring further position reports, those which were inactive, etc., required a considerable effort.** Another significant cause of failure was that all available flight plan data (particularly progress reports) was not always obtainable by the ARTCC personnel. The data had to be gathered by "looking over the shoulder" of the controller. It is understandable that information was missed under such conditions.

These difficulties were overcome in later tests by changing the method of obtaining and entering flight plans and progress reports. Radio communications between the High Altitude Sector and aircraft were monitored by MITRE personnel at the Barta Building; flight plans (usually containing three fixes) were copied from the radio conversations and immediately fed into the computer by means of the monitor teletype at Barta; and only in cases of uncertainty were telephone calls made to the ARTCC for supplementary information. These procedures yielded timely and complete flight plan data.

* The forms were patterned after the flight progress strip format. This was done for the convenience of the ARTCC personnel, since it introduced no new procedures.

** In order to screen flight plan data for usefulness to the test operator, some sort of status board showing active, proposed, etc., flights is required. Sorting the forms served the purpose of such a status board. In a more automatic system, this type of information might be organized by a computer and displayed to an operator.

2.3 Barta Operations

The two CHARM operational areas in the Barta Building were the Test Direction and Track Monitor Rooms.

2.3.1 Test Direction (TD) Room

System operation and tests were controlled from the TD room. Equipment on hand included an input-output teletype, remote display console, two situation display consoles of the track monitor type, headsets connected to the monitor radio, and telephone communications with all CHARM operating positions. During the later tests, four operating positions were set up in the TD room for a test director, flight plan coordinator, radio monitor, and teletype operator.

The test director was responsible for the over-all performance of the test. His primary concern was to insure that the system functioned properly. He also had the responsibility of accounting for flight plans not correlating with radar data.

The flight plan coordinator was responsible for giving new flight plan information to the track initiator and progress report information to track monitors. To accomplish this, he had to maintain a record of the radio communications and correlation status of system flight plans. This information was derived from radio channels and a situation display console. He could also telephone the ARTCC in the event of a garbled radio transmission or to get additional information. The information given the track initiator aided him in performing the initial correlation of flight plan track and radar data; that given the track monitor assisted in the reidentification of tracks which had lost correlation.

The radio monitor listened to the UHF transmissions between pilots and the High Altitude Sector and thus collected progress reports and flight plan revisions directly. When a flight plan was revised, the entire flight plan was copied and entered as a new system track. (In this mode of operation, the original flight plan filed at the center was never filed in CHARM storage. No cases were observed in which an entire flight plan was revised more than once.) When an aircraft which had filed a flight plan with the Boston ARTCC (but not with CHARM) made a progress report, the radio monitor

copied the present fix and time over it, the next fix and the estimated time over it, and the following fix, resulting in a three-fix flight plan for entry. Very little time was lost between the time the report was made and its insertion in the computer. This "rapid entry" mode of entry simulated the operation that might have been achieved if the actual controller or his assistant at the ARTCC had entered the flight plan data via teletype as soon as it was received. (This mode, of course, is opposed to the procedure of monitoring, copying, etc., by personnel other than the controller, which was the only method that could be used at the ARTCC). Although there was some compromise involved in utilizing only short, three-fix flight plans, this mode of operation permitted a more realistic observance of the possibilities of flight plan correlation. The ability to file standard flight plans from the ARTCC was demonstrated in the earlier operations. The teletype operator had the responsibility of filing all flight plan data given to him by the radio monitor.

2.3.2 Track Monitor (TM) Room

The four operating positions in the TM room were two track monitor (TM) positions, one track initiator (TI) position and one direction finding (D/F) position. The TI and D/F positions were added in the later stages of system testing.

The track initiator was responsible for the initial "matching" of flight plan position with radar data. He had a headset carrying the monitored radio frequencies so he could establish early correlation between reported position and radar data, in fact in some cases even before the flight plan had been filed in the system. This position was added to relieve the TMs of special attention required in initiating the correlation.

The track monitor positions were identical, with each TM having responsibility for half the geographical area. Their primary function was to correct the stored values of flight plan positions and speeds, so the resulting positions coincided with radar tracks. In the event that radar data was not correlating, the TM immediately labeled the track uncorrelated. He then had to continually monitor the progress of the extrapolated flight plan position and correlate the track again if it became clear that a radar trail existed for the aircraft. Handover between the two TM positions was accomplished verbally.

In its latter stages, CHARM experimented with a direction finding function designed to provide intersecting strobe data to help track monitors correlate radar and flight plan track data. Manually operated D/F stations at Westover and Otis Air Force bases were used, and military personnel at the stations monitored the High Altitude Sector frequency and noted call signs and bearings. This information was telephoned to the D/F coordinator at the Barta Building and inserted into the computer by switches. D/F readings were available only during radio transmissions by the pilots.

3 GENERAL RESULTS

In general, the results of CHARM operation were excellent. It is clear that SAGE data processing equipments and techniques can materially assist the high-altitude traffic controllers.

CHARM was an experimental system, and not necessarily a prototype for future integration. A major result of the experiment was a clear indication that successful integration should take the form of collocation--that is, the controller and track monitor should be located next to each other and should use the same computer, rather than the remote arrangement employed in CHARM.

Another major finding was that system testing is a major problem in integration, a problem comparable to the system design and implementation. The basic difficulty lies in effectively testing or using an experimental system while not compromising operation of the existing manual system.

An important and not insignificant result of the CHARM operation was the education acquired in air traffic control operation and SAGE-like data processing. A larger body of trained personnel now exists for future system integration efforts.

3.1 SAGE Assistance to Air Traffic Control

For a full evaluation of SAGE assistance to air traffic control as originally planned for CHARM, the ARTCC controller would have had to feed data into and make use of the outputs from the system. As noted, this mode of operation was never reached--due to the extreme difficulty of using an experimental system (such as CHARM) as part of an operational facility (such as the High Altitude Sector of the Boston ARTCC)--and CHARM was run independently of the ARTCC controller. For these reasons, the intended demonstration of SAGE assistance was limited to observing the potential of CHARM at the operating stations at the Barta Building.

In accepting and processing air traffic control data and in generating displays and output teletype messages, CHARM demonstrated an ability to help the controller perform his duties. It also proved that the use of teletype equipment is an excellent and inexpensive means of flexible communication with the computer.

During CHARM operations, the requirement for close coordination of the controller and track monitor presented a problem. Communication between these two operators could best be afforded by having the controller and track monitor sit beside each other. This arrangement, requiring collocation, would result in a more effective display of the air situation to the controller, and thus increase the assistance the system was giving him.

3.2 Radar Data Correlation with Flight Plans

In the initial periods of operation, the correlation process was unsatisfactory; the later method of collecting flight plans by radio led to satisfactory correlation. In general, correlation was better in IFR conditions than in VFR. Under VFR conditions, large deviations between flight plan and radar data along and lateral to the flight path, were not unusual.

Three functions of CHARM that affected the correlation process were track monitoring, flight plan extrapolation, and radar inputs.

3.2.1 Track Monitoring

Track monitoring was generally good. The greatest source of trouble was in following aircraft which were already in radius type flights either at the beginning of a test period or which reported having gone into a non-scheduled radius type flight, after the fact. A second major difficulty was that a monitor had to maintain continuous manual tracking. Automatic tracking, as in SAGE, will be mandatory if a monitor is to carry a load of more than three or four aircraft. With automatic tracking, a monitor would no longer have to devote continuous and equal attention to all tracks. The greatest need for automatic tracking arises from monitoring radius flights or the marginal cases where the flight plan is vague about the exact route. Automatic tracking would also detect and notify a monitor when special situations occur that need his careful scrutiny.

It was found in CHARM that a controller had information that would have been useful to the track monitors. This information results in part from the controller's experience in traffic flow, but primarily from his direct communication with the cooperating aircraft. Effective coordination between controller and track monitor, such as might be achieved by collocation, could resolve most, if not all, abnormal tracking situations. For example, once an aircraft was lost, there was no information available that would allow for positive correlation by the track monitor. If an aircraft were under actual control from a joint monitor/controller position, identification might be established by turning the transponder off and on, if available, or by requesting the aircraft to fly preplanned maneuvers.

An analysis of the track monitoring function led to the following conclusions:

- a. The display console used by a TM should have an off-centering and expansion capability to alleviate the problems caused by crowded displays.
- b. The TM should be able to make trial changes; that is, be able to create a tentative track which can be monitored until positive correlation can be established.
- c. Track status information should be made available to a TM. The status information might include the last ATA (actual time of arrival) fix and the CTIN (cumulative time increment which changes the filed or computed ETA at the next fix). This status information should summarize the major factors, used by the computer and filed by the controller, that affect the following of a particular aircraft.
- d. The change speed action was difficult to use because the filed speed was not "remembered" and hence the action could not be reverted. A new speed was used to determine aircraft position from the last ATA fix, thus resulting in an undesirable position change which varied as a function of time since the last ATA.
- e. The route display was very helpful. However, it was felt that the display could be better defined so that the route of flight can be readily established with little or no interpretation required on the part of the TM. Indication of the route direction would be useful, as would the identification of the turn points.

- f. A TM was able to move a flight plan position to radar data and have the program fly the aircraft to the next fix, with the ETA at the next fix being used as a basis for flight plan extrapolation. In order to avoid absurdly high incremental position changes (having the same effect as a very high speed), some limit should be placed on the distance a flight plan position can be moved in correlating with radar data.
- g. A TM should be alerted automatically when a flight plan is first assigned to him. He can thus concentrate on the tracks already assigned to him and need not be concerned with looking for new tracks entering his area.
- h. The (initial) correlation and track monitoring functions should be separated. Although this separation was not planned in the original CHARM design, it was used satisfactorily in later operations.

3.2.2 Flight Plan Extrapolation

The rather simple extrapolation process used in CHARM was quite effective. Extrapolation statuses derived from filed flight plans or resulting from TM actions provided the flexibility required in tracking high-altitude flights. The following points are noted:

- a. Winds aloft should be considered when making initial fix calculations. The effect can become significant when successive fixes are far apart or progress reports are lacking.
- b. Proposals to derive wind components from the difference between estimated and actual arrival times at a fix should be reconsidered in view of the fact that flight paths can deviate widely from those used as a basis for estimating the time of arrival.
- c. A more sophisticated time delay should be considered for aircraft climb-out delay. Such a departure delay may become a decisive factor for aircraft climbing out on complicated departure routes.
- d. Aircraft often made substantial changes in direction at fixes, but the extrapolation program improperly "flew" them in a straight line from fix to fix and neglected the turning radius. Turning delays might also be used in the calculations when aircraft change flight path directions.

- e. A change of track position resulted when a progress report contained a fix time different from that already stored. Accordingly, correlation status should be considered before using position reports to affect flight plan positions. Whenever a track is changed in this manner, the track monitor should be notified.
- f. Flight plans should not be dropped automatically but only at the request of the monitor, and he should have a display to help him drop them.

3.2.3 Radar Inputs

Radar data was generally satisfactory, although mapping at the sites was hampered by the limited scope of the tests and concentration on other aspects of CHARM. This led to occasional ambiguous tracking and uncorrelated tracks. The later tests were conducted after Mark X SIF was put into operation, and since operational use of beacons had not been fully established, a certain amount of confusion resulted. This degraded correlation, but it was not considered serious. The confusion is expected to disappear with the introduction of a definite SIF employment plan.

Testing produced the following conclusions about radar and beacon inputs:

- a. The display of radar data history is very useful in the correlation process. The best method of generating and displaying radar data is a problem that needs more study.
- b. Mark X and SIF data provide a significant input to a tracking or track monitoring function. The data is particularly useful because of its coding, increased reliability, and range.

3.3 New Equipment and Techniques

3.3.1 Teletype

Perhaps the most significant aspect of the CHARM tests was the success of the on-line teletype input technique. The equipment provided flexible, inexpensive, efficient communications between the computer and the operator in the controllers' language. Error detection proved very useful and in a more sophisticated system should be expanded to give the operator more information. In CHARM when an error was found

in a message group, the operator was told an error had occurred and what his last correct group had been. He should also be told the nature of his error: fix not stored, airway does not list appropriate fix, or a group has been omitted.

General conclusions about the teletype system are:

- a. The use of a single teletype machine for input and output, rather than a single machine for each as used in early CHARM operations, permits easy correlation between input messages and computer response. This feature is very useful in manual correction of computer-detected errors and in referring to messages already filed.
- b. The letter/figure shift proved to be an annoyance as well as a source of many typing errors. Future teletype input systems should attempt to minimize susceptibility to this type of error.
- c. In a round-robin type of flight, a given fix may appear in the route of flight more than once. This led to a confused situation whenever an error message involving the fix was generated. It was also difficult to properly insert a progress report which referred to one of these repeated fixes.
- d. Progress reports should utilize all the information that is available; that is, present time over present fix, estimated time over the next fix and the following fix. It is possible that effective use of this information could lead to a solution to the problem of repeated fixes.
- e. If an item is omitted in a flight plan or an error is committed, the operator should be able to insert the item or correct the error without retyping the rest of the message.
- f. Provision should be made to accept additional types of fixes and routes. An aircraft might report its position as abeam of a fix, a route might be specified as a bearing from a fix (320° from Boston), or an airway might be specified from a fix not on the airway (BOS V13. . , where Boston does not lie along V13).

3.3.2 Remote Display

The flicker-free, persistent, and daylight-viewing features of the remote display were quite satisfactory. However, because the ARTCC never prepared to act in CHARM testing, beyond supplying input data, and because of unsatisfactory maintenance performance of the initial model, the remote display was never installed at the center. Deterring factors were:

- a. Characters were too large, and the scope was easily cluttered when used for many aircraft movements (a new Charactron matrix could have solved this problem if time had permitted).
- b. Overlapping data situations could not be easily resolved because there was no expansion and off-centering capability.
- c. Balance between brightness and persistence required adjustment procedures that were too complicated.

3.3.3 Direction-Finding

Direction-finding equipment was not used enough to analyze its usefulness. It was first used late in CHARM operations, when no time was available to install efficient telephone links between the D/F stations and Barta Building. It had been intended to obtain a "fix" from bearing information from two stations, but simultaneous communication with the D/F coordinator was seldom possible. Direct telephone lines or, better still, a direct entry into the computer should be provided.

4 SUMMARY DATA

Although tests in the early mode of CHARM operations were not intended to yield quantitative data, page copy of teletype messages permitted an analysis of errors (see Section 4.1). A log of track correlation status produced the data in Section 4.2. All data covers only seven test periods in the early phases of CHARM operation.

4.1 Teletype Input (See Figure 1)

All manual teletype errors could be grouped into two categories, typing and information.

4.1.1 Typing

The operator had the correct information but made a mistake inserting it into the computer. Three general classes were observed: spelling, figure/letter shift, and format.

- a. Spelling - The operator typed BAS instead of BOS. This was serious if a BAS fix existed in computer data storage.
- b. Figure/letter shifts - The operator forgot to strike the figure or letter shift key. Although quite common because of the frequent shifting required by the message format, this type of error was readily detected by the operator. Figure 1 shows that operators found 76 of the 83 made.
- c. Format - The typist did not comply with message format. For example, aircraft type or speed was inadvertently omitted. This type didn't happen frequently and wasn't considered serious, since the computer processed data only as far as the last correct group.

4.1.2 Information

A message was correct in format and content, but included data not directly applicable to the computer tables or program design. The general classes are illegal and inactive.

- a. Illegal - A message contained information not prestored in static data tables. The most common illegal entry was filing an airway which did not have the access fix stored. For example, a route was typed as . . . BOS G5 ALB. . . If G5 didn't list either BOS or ALB, the entry was illegal. These errors were caused primarily by the complex structure of airways and fixes.
- b. Inactive - Filing a progress report (unless it was intended to activate a flight plan) or a position request message about a track not yet active. The most common source of this error was a position request for a flight that had left the system.

4.2 Flight Plan Data Correlated

Ninety-seven flight plans were entered during the seven test periods. Seventy-seven were processed for correlation by the track monitors, the remaining 20 being either inactive or out of the area. As shown in Table II, 53 tracks, or 69% of those processed, were judged to be successfully correlated. These represented a large variety of situations of both VFR and IFR flights.

Correlation failures resulted primarily when flight plans were filed after the aircraft had gone into radius or warning area flights or when no radar data was observed near the flight paths. This absence of radar data may be due either to "blind areas," where there was no radar coverage, to aircraft not following flight plans, or to incorrect flight plans. Other causes were flight paths through congested areas, in-flight route changes, and no progress reports being made to the ARTCC.

Messages Filled - 480

Errors Detected - 217

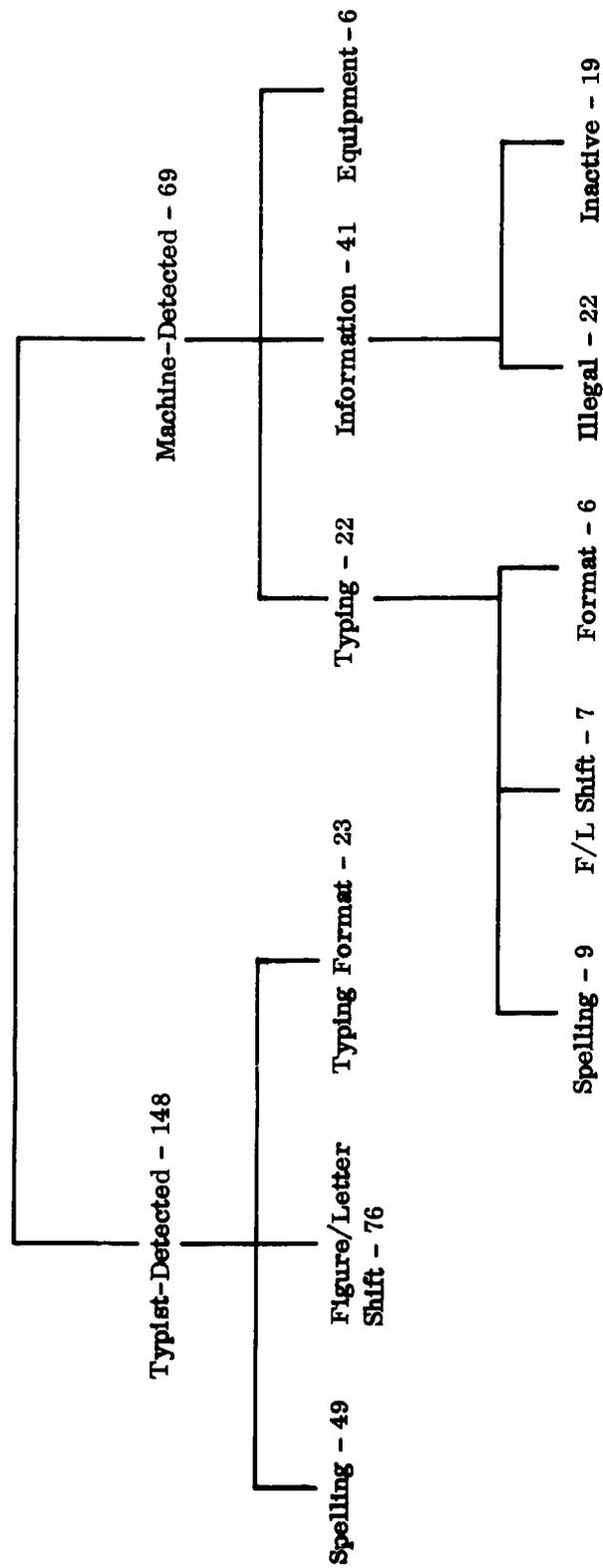


Fig. 1. TELETYPE INPUT. Data gathered in seven test periods is broken down to show what types of errors occurred. The typist detected 148, or approximately 70 per cent. (The computer would have found them even if the operator hadn't.) Operator training would probably cut the number of errors significantly.

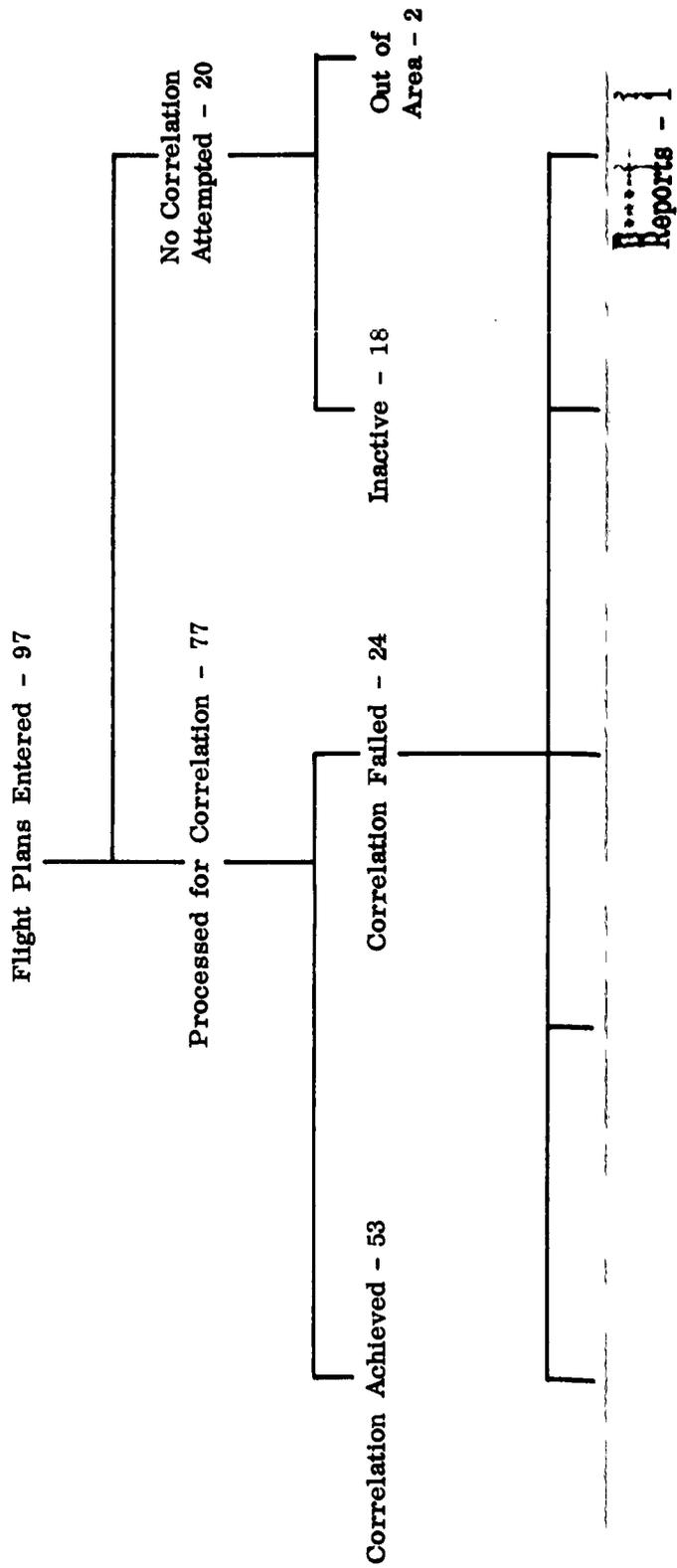


Fig. 2. CORRELATION (Data from seven test periods)