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**Project Report**
**ATC-84**

# Airborne Measurements of ATCRBS Fruit

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16. Abstract

Airborne measurements of ATCRBS fruit (asynchronous replies from ATCRBS transponders) are described. These measurements were undertaken to provide a more firm basis for assessing the interference impact of ATCRBS fruit on airborne 1090 MHz receivers (as in BCAS). Fruit rate measurements were performed with an instrumented aircraft flying along the East Coast from Boston to Washington and in the Los Angeles Basin. The results of these measurements are reported here, with fruit rates given as a function of altitude, geographical location, and receiver threshold, for receptions on both top-mounted and bottom-mounted aircraft antenna. The highest observed fruit rates, approximately 10,000 replies/sec, occurred in the LA Basin.

To complement the measurements, a first-order fruit prediction model is defined. Predictions of this model are compared with the measurements, generally showing favorable agreement in absolute fruit rate, in power distribution, and in the functional dependence on traffic density.

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## 1.0 INTRODUCTION

ATCRBS* fruit is a significant form of interference which may degrade the performance of FAA and military air traffic control equipment operating at 1090 MHz. The colloquial term "fruit" refers to asynchronous transponder replies reaching a receiver -- asynchronous in the sense that they are not replies to interrogations associated with this receiver.

In the technical development of BCAS**, particular attention has been given to the effects of ATCRBS fruit. It was anticipated that the fruit rates received by an airborne system with omnidirectional antenna could be quite high, particularly when flying in areas of high traffic density and/or high rates of interrogation. The initial assessments of fruit and its effects on BCAS were primarily analytical (ref. 1). To provide a more firm basis for this aspect of BCAS development, M.I.T. Lincoln Laboratory undertook, with FAA sponsorship, a program to measure fruit rates while airborne. The goal of this program was to measure the rate and power distribution of fruit as it impinges upon both bottom-mounted and top-mounted aircraft antennas, and to obtain these results as functions of altitude and geographical location.

The measurements were performed along the East Coast from Boston to Washington and in the Los Angeles Basin. High traffic densities in LA suggested that the highest airborne fruit rates might be experienced there. Results of this measurement program are presented in this report.

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* Air Traffic Control Radar Beacon System.

** Beacon-based Collision Avoidance System.

## 2.0 FRUIT MEASUREMENT TECHNIQUE

The Airborne Measurements Facility (AMF), an M.I.T. Lincoln Laboratory instrumented aircraft used in an earlier program, provided a means for measuring and recording fruit while airborne. Measurement hardware and software are illustrated in Fig. 1. The AMF detects pulses received on top and bottom mounted antennas and records this pulse-by-pulse information on magnetic tape in a digital format. Time of arrival, pulse width, and received power level (for each of the two antennas) are recorded for each pulse, along with data giving the time of day and aircraft location. A more detailed description of the AMF is given in ref. 2.

In the airborne fruit measurements, data rates were kept within manageable bounds by gating the airborne receiver on and off according to a preselected duty factor. Specifically, the receiver was turned on for 500 μs intervals occurring at a rate of 11.8 per second.

The magnetic tape recordings were returned to the ground for later computer processing. This processing includes passing the pulse data through an ATCRBS reply detector (implemented in software). The particular reply detector used is of an advanced design, developed in the DABS (Discrete Address Beacon System) program. The replies are then sorted according to their received power levels, and finally these sorted replies are counted to determine fruit rate.

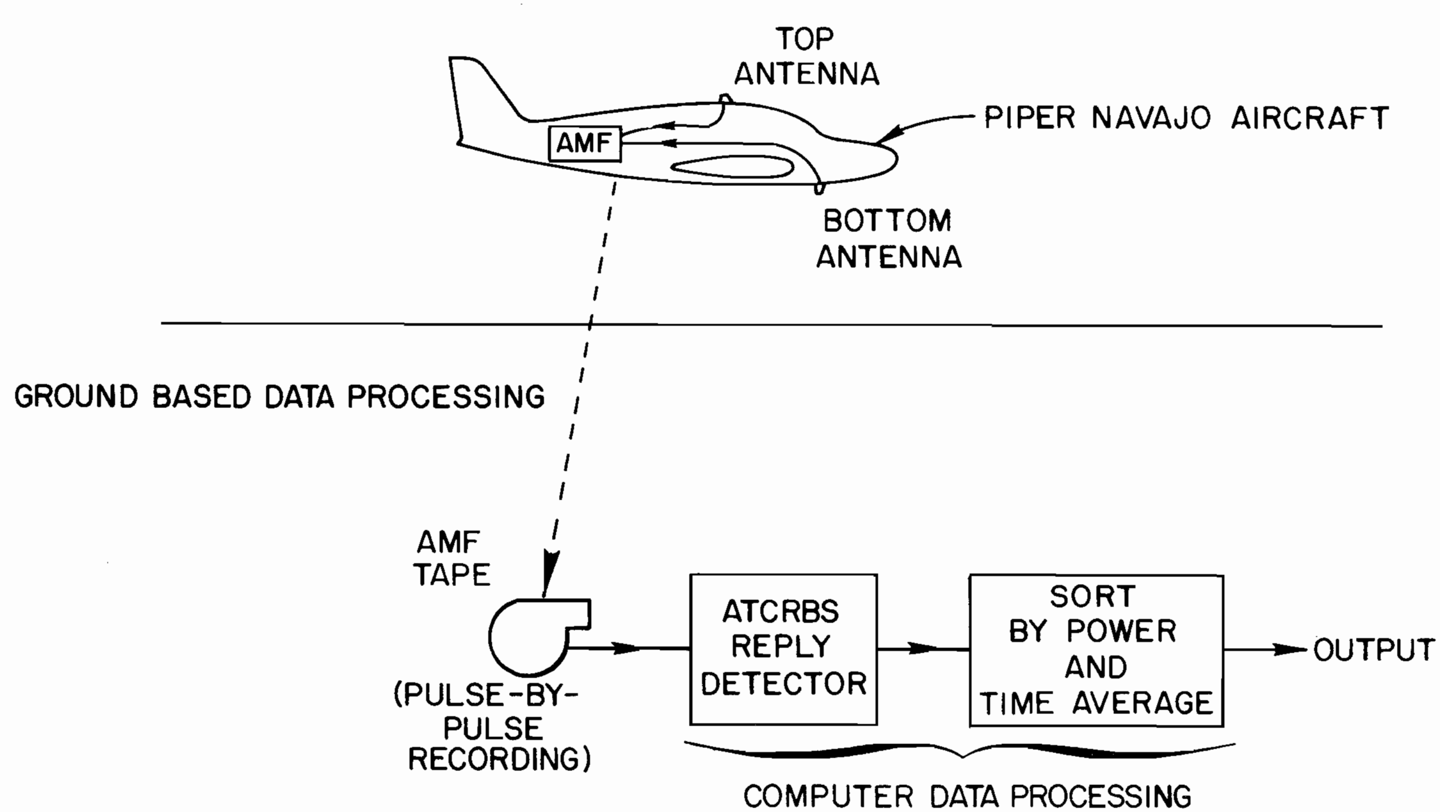


Fig. 1 Measurement hardware and software.

## 3.0 MEASUREMENT RESULTS

### 3.1 LA Basin Measurements

Fruit rates measured during a flight in the LA Basin are shown in Fig. 2. Each point denotes the average rate over a 10-second period. Average fruit rate is computed as the total number of recorded replies in the 10-second period divided by the total of the listening window times in that same 10-second period. Measurements began near Long Beach and proceeded as the aircraft flew a northwesterly course passing over Los Angeles International Airport (LAX), into the San Fernando Valley, and over the Van Nuys Airport. The flight path is sketched in Fig. 3. The results in Fig. 2 are given for three different receiver thresholds (implemented in the computer processing) in order to indicate the distribution of fruit with respect to power level. Both top- and bottom-antenna receptions are shown.

Fruit rates from 1000 to 10,000 replies per second were measured (see Fig. 2) depending on aircraft location and receiver threshold, with about an order of magnitude change in rate for a 10 dB change in threshold. Rates received on top and bottom antennas are seen to be about the same (for this flight at 4500 ft. altitude). How these results compare with what might be expected is addressed in Section 4.

It is important to determine how airborne fruit rates vary as a function of time. If variation with time were very large, other dependences of interest, such as dependence on receiving antenna, receiver threshold, and aircraft location, would be masked. To determine this variation, a series of fruit measurements were carried out with the aircraft flying in a circular pattern, so as to measure from generally the same location. With radius about 4 nmi and speed about 150 knots, the time for one orbit was about 10 minutes. The aircraft was flown at zero bank angle in order to simulate the condition of straight-and-level flight.

Results of this measurement are shown in Fig. 4. The three graphs all pertain to circular orbits which are nominally identical. The first and second orbit were flown in immediate succession, while the 3rd orbit was about an hour later. Thus, in this figure, one can see the amounts of fruit rate variation which occurred for time passages of 10 minutes and one hour. Furthermore the variations seen from one point to the next (in this figure and in Fig. 2) may also be taken as an indication of the variability with time over a 10 second period, during which time aircraft location is nearly fixed.

Additional repeatability data is shown in Fig. 5. These results are from three nominally identical flights over the Long Beach to Van Nuys flight path (shown in Fig. 3).

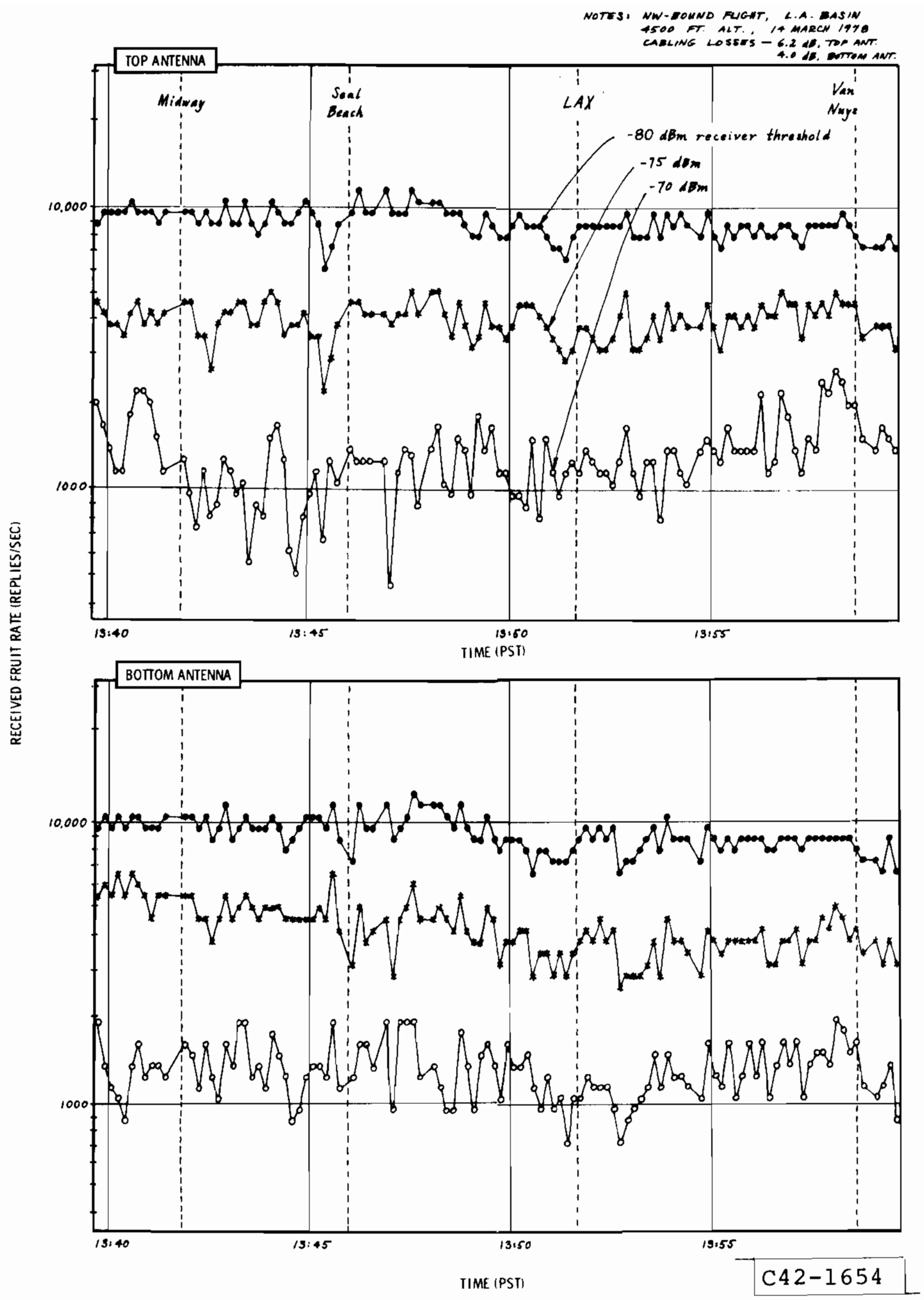


Fig. 2 LA Basin airborne fruit receptions on top and bottom mounted antennas.

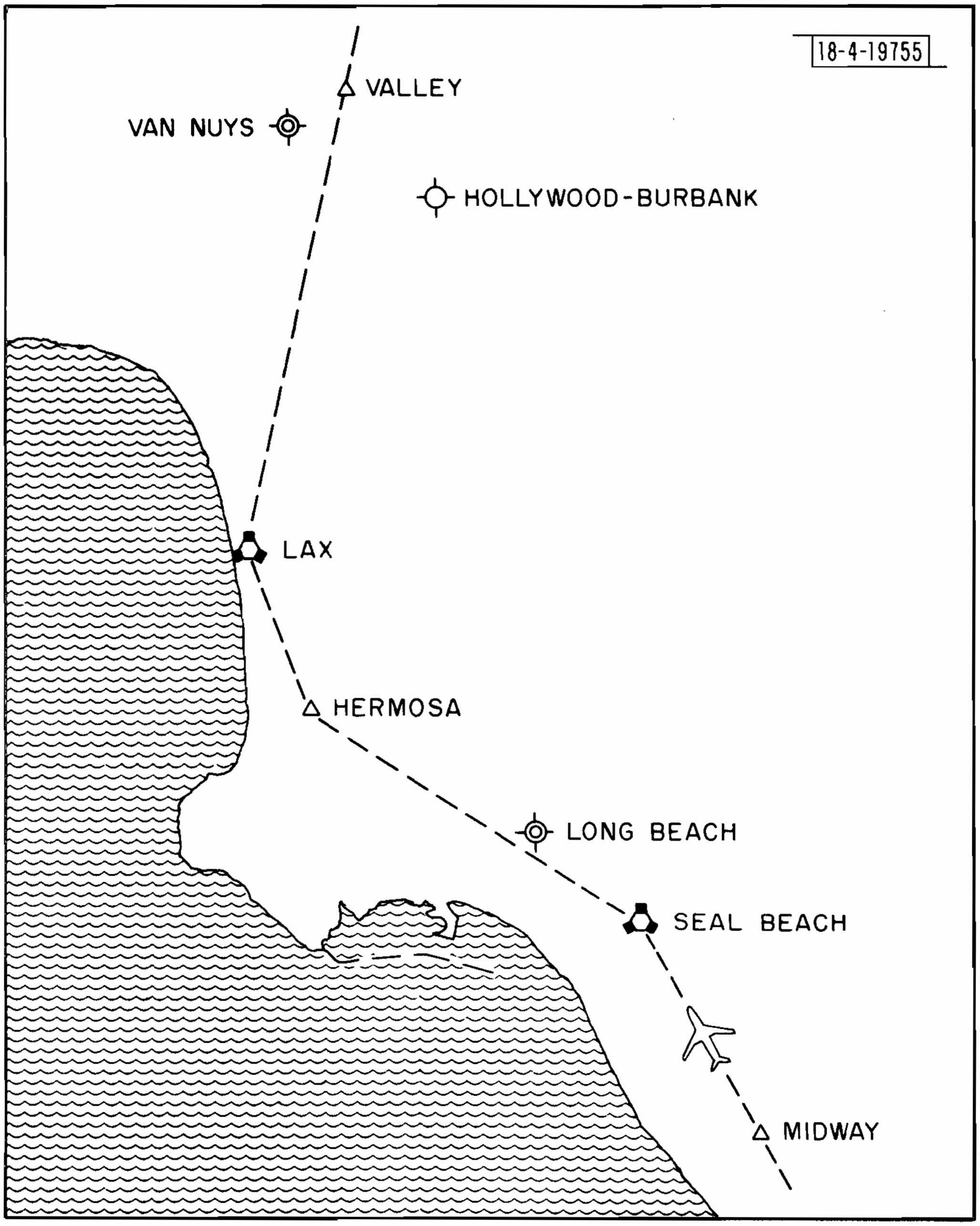


Fig. 3. Flight path during Fig. 1 fruit measurements.

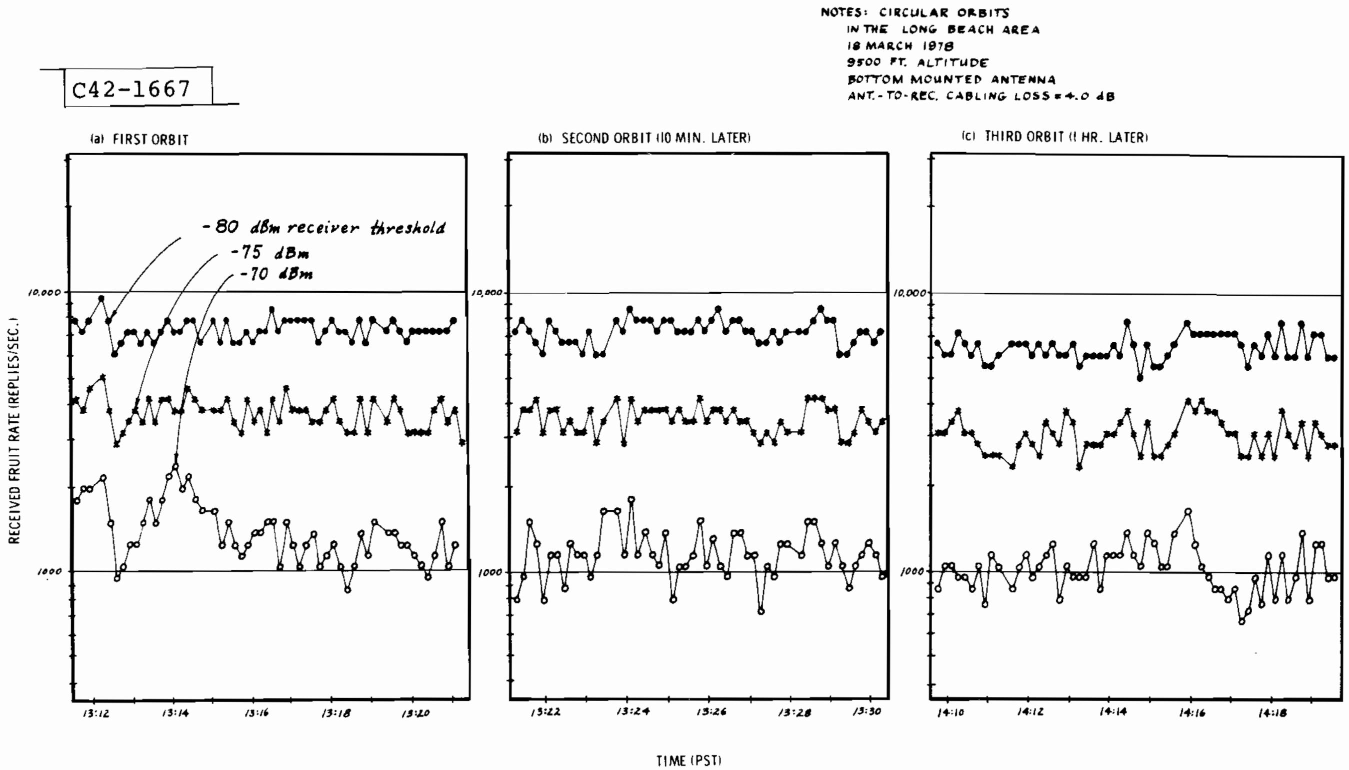


Fig. 4 Fruit rate measurements addressing the subject of variations as a function of time (aircraft flying in a circular pattern).

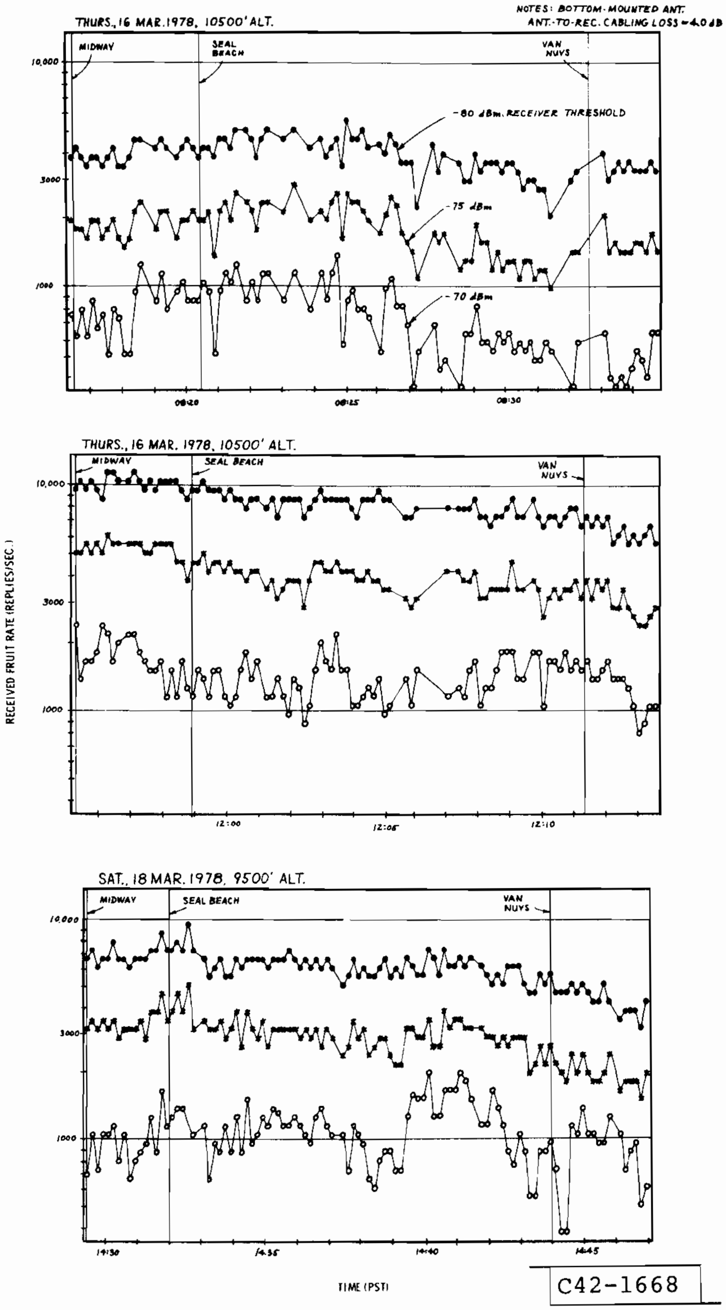


Fig. 5  Repeatability of fruit measurements for a Long Beach to Van Nuys flight.

The results in Figs. 4 and 5 indicate that the fruit rates do vary with time, and yet these variations are sufficiently limited that we can meaningfully look for functional dependences of fruit on other factors.

The functional dependence of fruit on aircraft altitude is of interest and was addressed specifically in some of the measurements. This is of interest because of an expectation that at high altitude, a top mounted BCAS antenna would provide a favorable discrimination between desired signals, arriving from nearly coaltitude aircraft, and fruit interference, primarily coming from lower altitude aircraft. Thus, the expectation was that with increasing altitude, top antenna fruit receptions would decrease.

Accordingly, the circular flights were carried out at a number of different altitudes. Results are shown in Fig. 6, where each point plotted is the median value of the 10-second fruit rate measurements over the full 10-minute circular orbit. The receiver threshold values plotted here have been referred to the antenna so as to make the plot generally independent of the cabling losses from antenna to AMF.

The results indicate a weak altitude dependence of top-antenna receptions, with this dependence occurring only at relatively high received power level. However this effect does not appear to be large enough to be significant. To first order, the results indicate that fruit rates are not a significant function of altitude (within the altitude and threshold limits plotted), and are about the same on top and bottom antennas.

### 3.2 East Coast Measurements

Results of East Coast fruit measurements are shown in Fig. 7 (flight from New York to Washington and Fig. 8 (flight from New York to Boston). The flight paths are illustrated in Figs. 9 and 10.

These measured fruit rates are substantial, and yet are not as high as the rates measured in the LA Basin.

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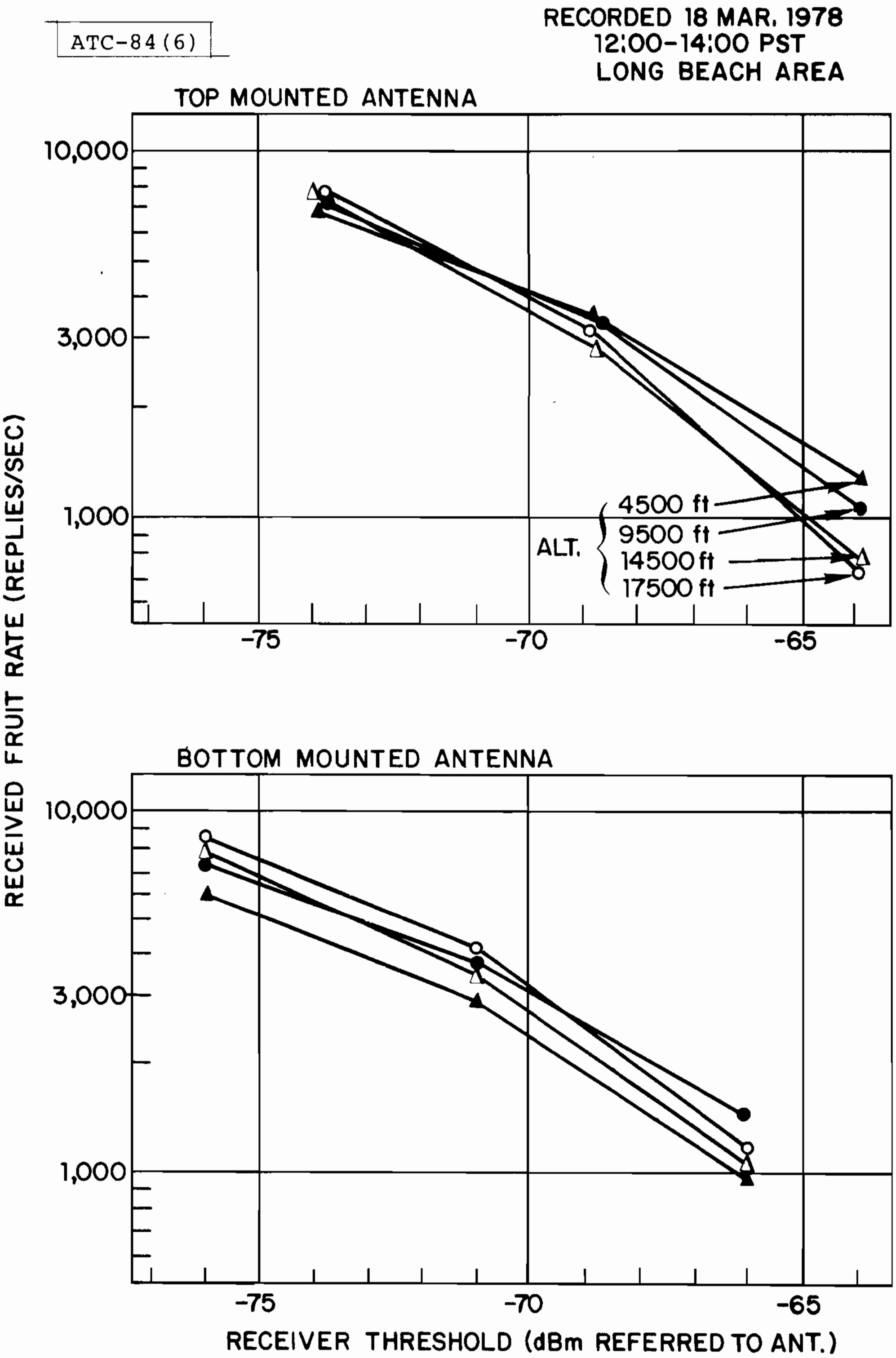


Fig. 6 Effects of altitude on fruit receptions.

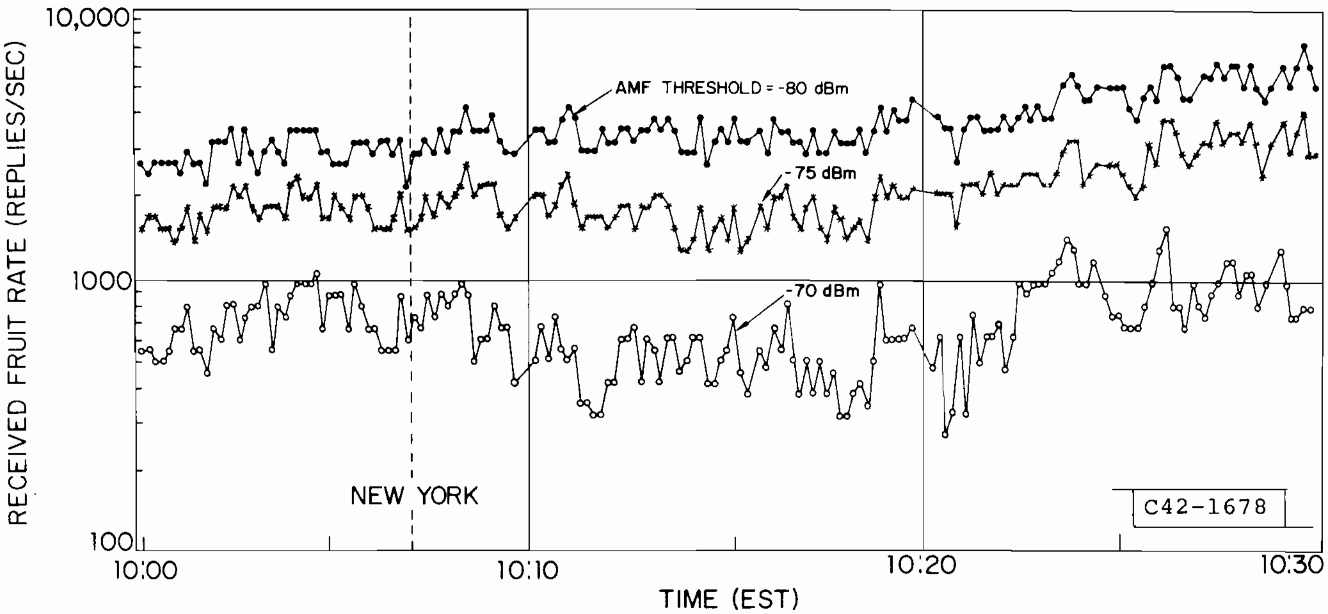


Fig. 7(a) Airborne furit measurements - N.Y. to Washington flight (bottom antenna only).

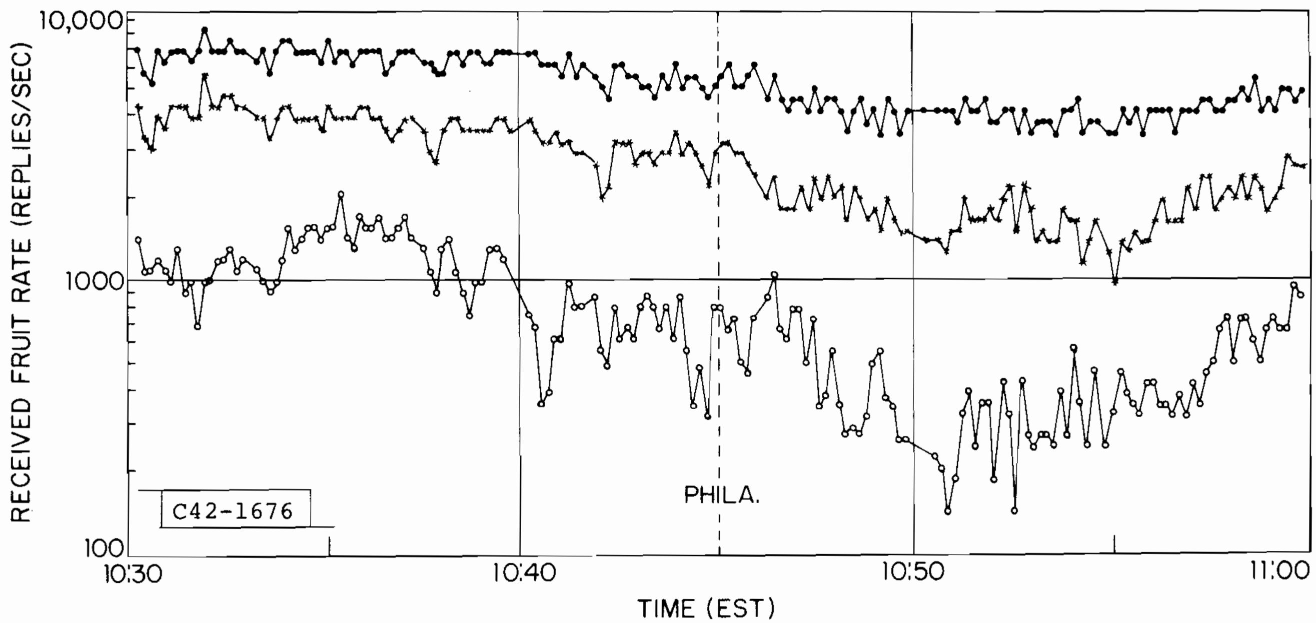


Fig. 7(b) Airborne fruit measurements - N.Y. to Washington flight (continued).

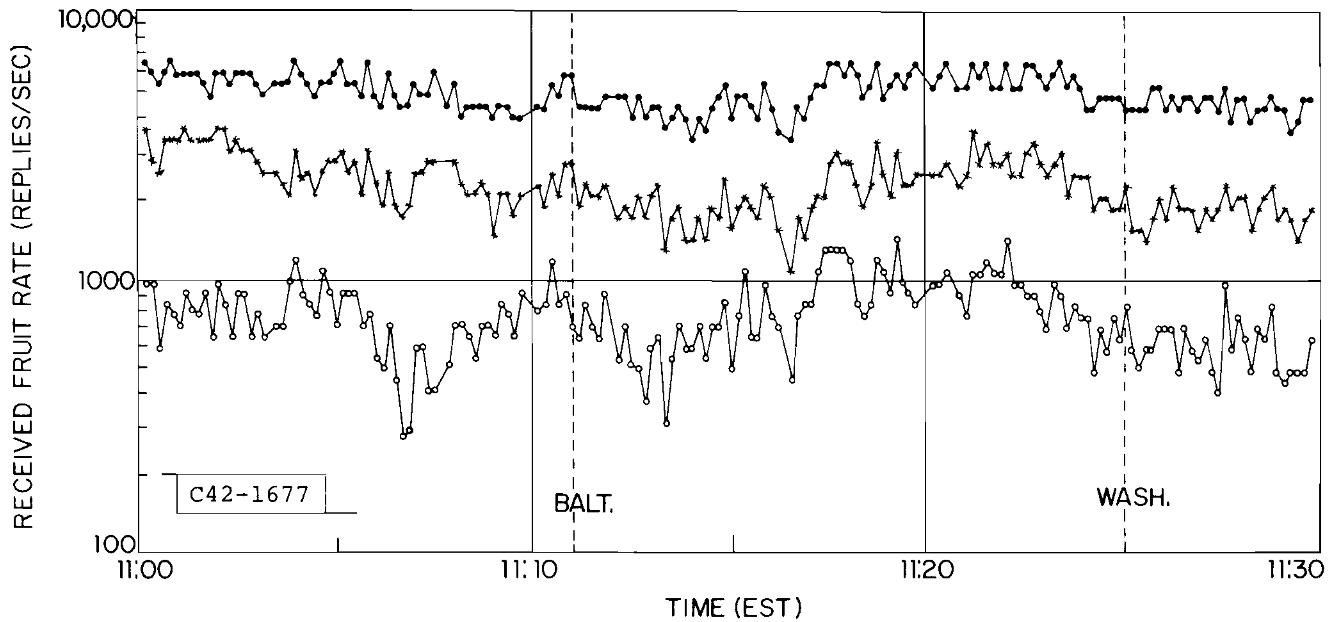


Fig. 7(c) Airborne fruit measurements - N.Y. to Washington flight (continued).

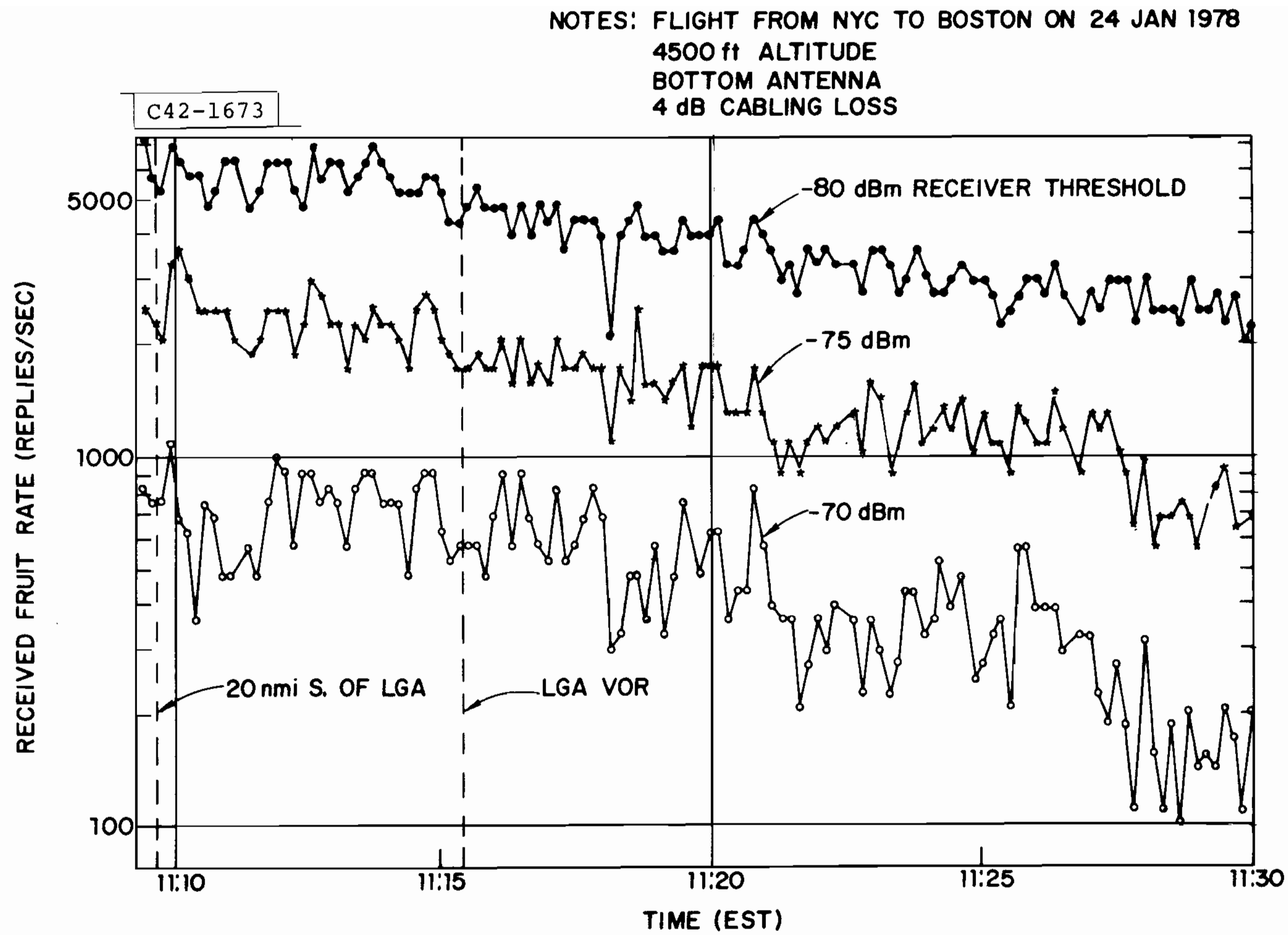


Fig. 8(a) Airborne fruit rate measurements - N.Y. to Boston flight.

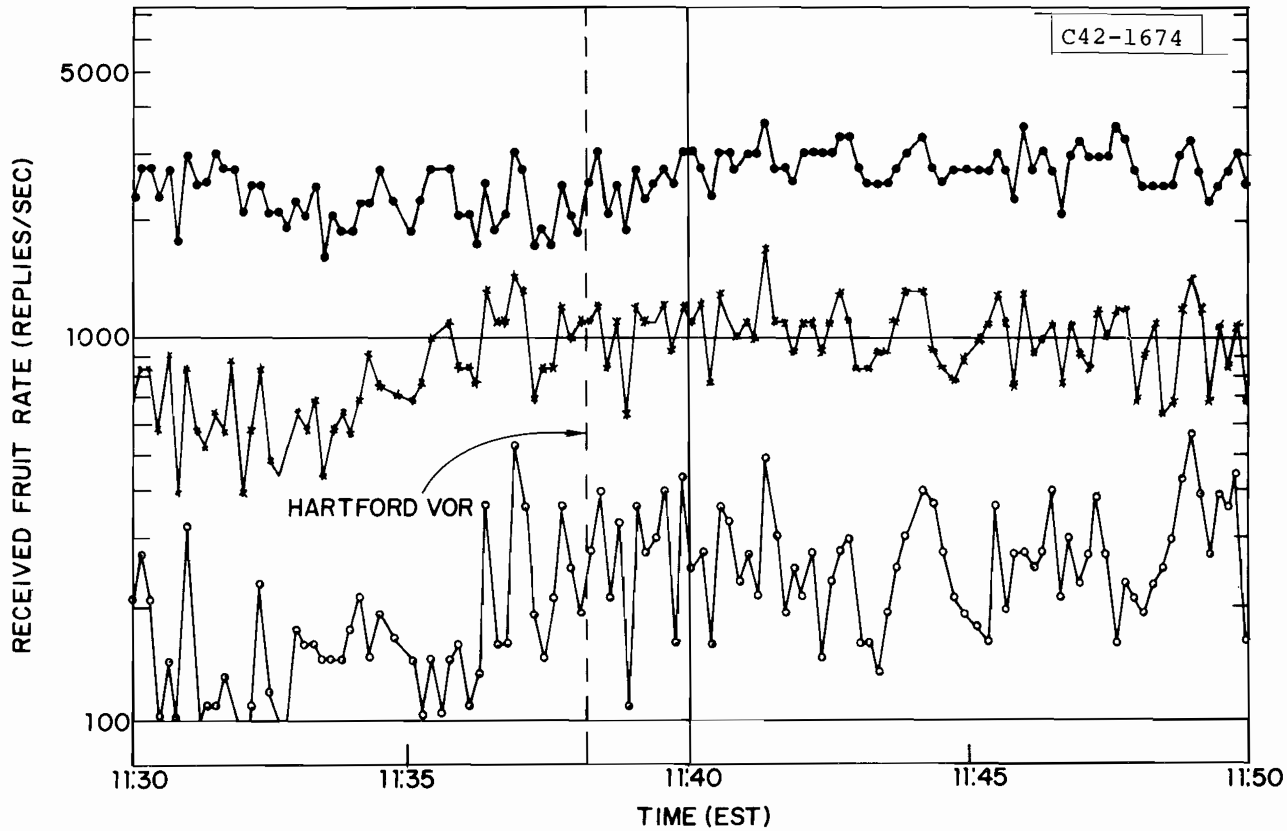


Fig. 8(b) Airborne fruit rate measurements - N.Y. to Boston flight (continued).

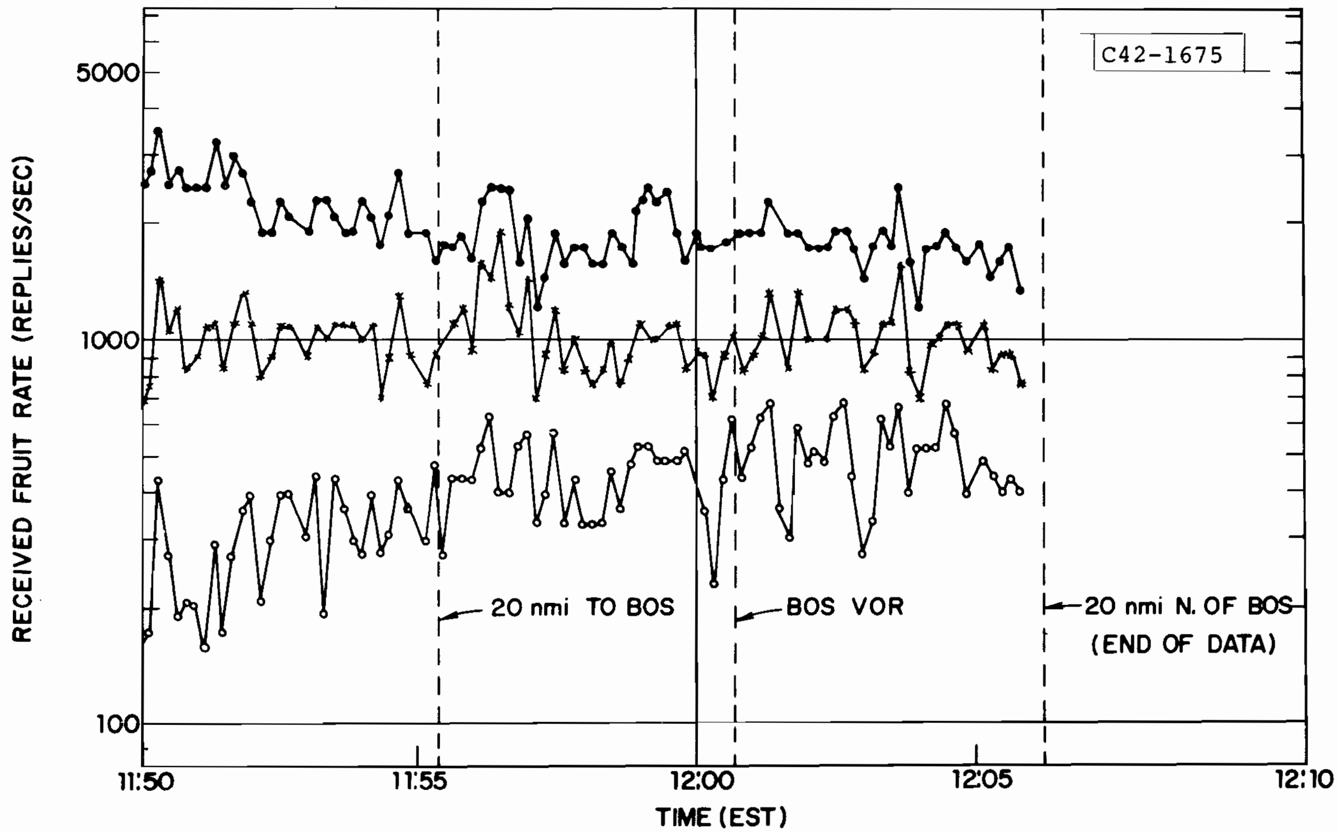


Fig. 8(c) Airborne fruit rate measurements — N.Y. to Boston flight (continued).

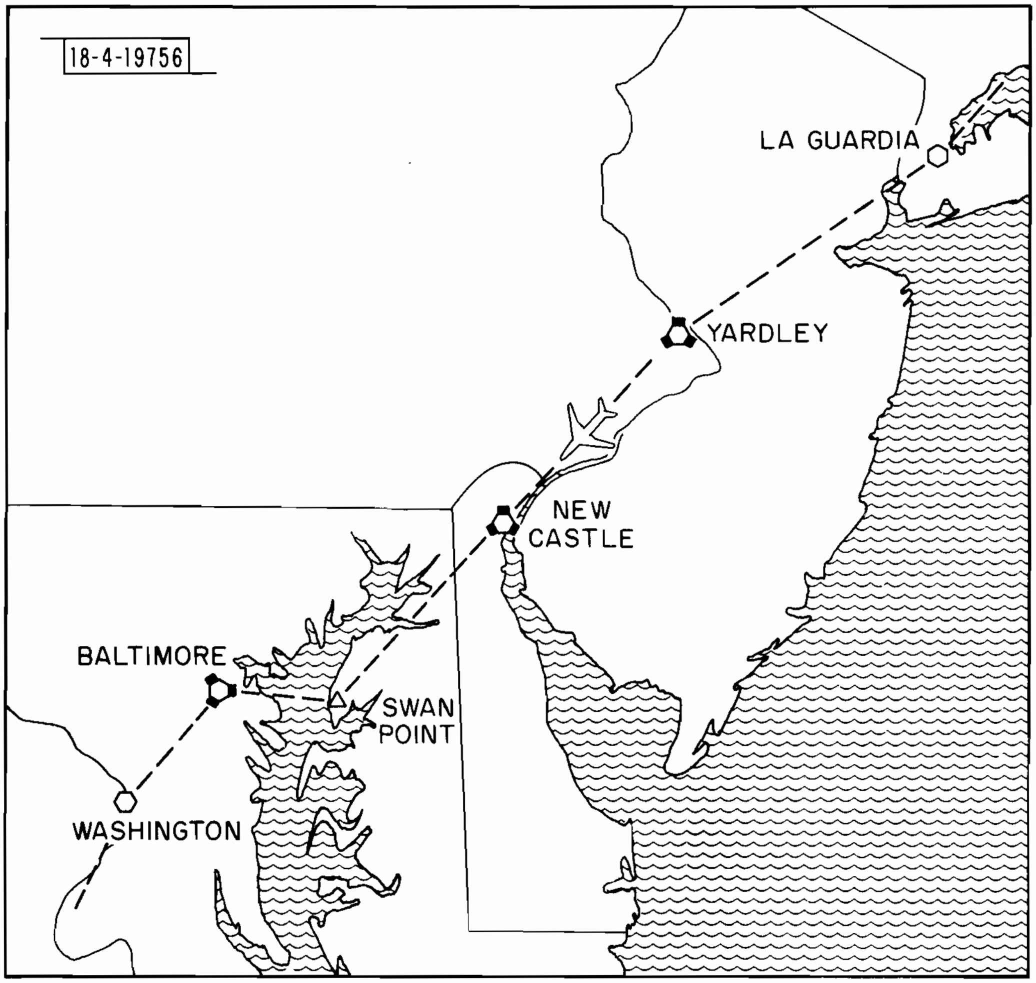


Fig.9. New York to Washington flight path during Fig.7 fruit measurements.

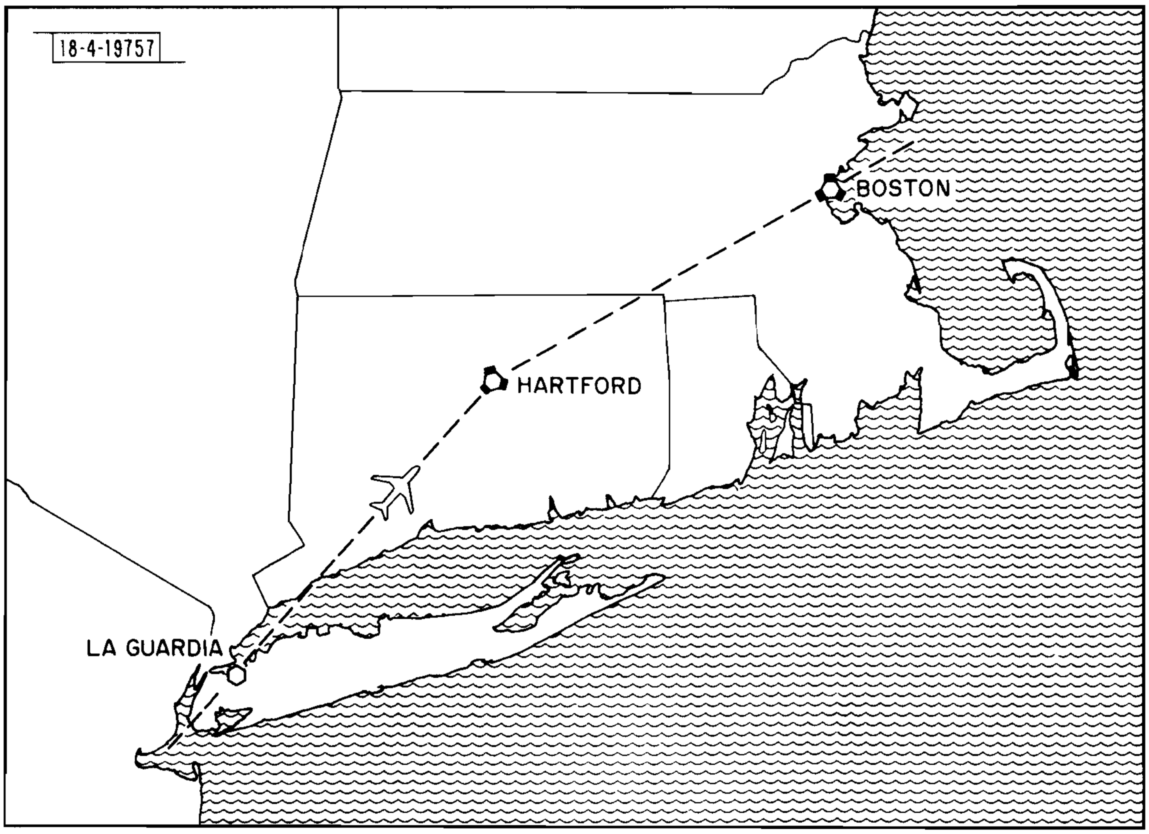


Fig.10. New York to Boston flight path during Fig.8 fruit measurements.

## 4.0 MODEL VS. MEASUREMENT COMPARISON

Figure 11 defines a simplified model for calculating airborne fruit rates. This model was proposed several years ago, and has been used in analytical and simulation BCAS development activities (for example, in ref. 1). Note that in spite of its simplicity, the model predicts fruit rates as a function of both traffic density and receiver threshold. In fact, the model predicts that fruit rates are a strong function of receiver threshold. For example, if receiver sensitivity were increased by 6 dB in uniform-in-area traffic, fruit rate would quadruple.

Derivation of this model is as follows. Beginning with the three idealizations given in Fig. 11, the next step is to determine the range within which fruit receptions are detectable above receiver threshold. For a receiver threshold of -74 dBm referred to the antenna, which is the nominal value for a BCAS receiver (ref. 3), the maximum link range R depends on the following factors.

| | |
|---|---|
| transmitter power | 57 dBm |
| transmitting cabling loss | 3 dB |
| transmitting ant. gain | 0 dB |
| receiving ant. gain | 0 dB |
| receiver threshold | 74 dBm |
| path loss, 20 log $4\pi R/\lambda$ | 128 dB |

The solution for R is 30 nmi. Under these conditions, fruit is received from all aircraft within a range of 30 nmi. Letting N(R) denote the number of ATCRBS-equipped aircraft within range R, and f = 150/sec be the average per aircraft ATCRBS reply transmission rate, results in a total received fruit rate of 150 × N(30 nmi).

The assignment of f = 150/sec as the average transponder reply rate was based on 1973-4 interrogation rate measurements reported in ref. 4 and 5. These measurements indicate that interrogation rate (and therefore transponder reply rate) varies as a function of aircraft location, reaching values of 300 to 500/sec around major cities (New York, Philadelphia, Washington, and Los Angeles) and dropping to around 100/sec for extensive areas outside of these cities. Recent (December 1977) measurements of the interrogation environment on the East Coast (ref. 6) indicate that the average interrogation rate between Boston and Washington is approximately 75/sec. This result suggests that improvements in ground based equipment may have significantly reduced the interrogation environment over the past several years. The assignment of 150/sec for fruit rate prediction was a somewhat arbitrarily selected mid-range value based on the earlier data. The suitability of this assignment

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IDEALIZATIONS:

1) REPLY RATE = f replies/sec, A CONSTANT FOR ALL AIRCRAFT (TYPICALLY f = 150/sec)

2) TRANSMITTER POWER = 500 w LESS 3 dB CABLING LOSS FOR ALL AIRCRAFT

3) AIRCRAFT ANTENNA GAIN = 0 dB IN ALL CASES

RESULTING FORMULA:

$F = f \times N\ (30\ \text{nmi})$

$N(R)$ = NO. OF AIRCRAFT WITHIN RANGE R

THIS GIVES THE TIME AVERAGE RECEIVED FRUIT RATE COUNTING ALL REPLIES OVER -74 dBm REFERRED TO THE ANTENNA. TO APPLY TO ANY OTHER THRESHOLD, CHANGE THE RANGE FROM 30 nmi BY 2:1 FOR EACH 6 dB CHANGE.

Fig. 11 Simplified model for airborne fruit rate.

can best be judged by comparisons of these predictions with actual fruit measurements.

Traffic density figures that can be used in this fruit prediction model are shown in Fig. 12. The data, from ref. 7, shows N(R) which is the number of aircraft within a range R. Results are given for 13 different traffic samples, and in each case, the geographical point about which N(R) is computed was selected as the location of peak traffic density. In the cases of the LA Basin traffic samples, this center point was in the Long Beach area. In fact, it was the knowledge that traffic density peaked in the Long Beach area that motivated the choice of this area for most of the airborne fruit measurements. Figure 12 also gives for comparison the traffic distribution of Mitre's LA high density traffic model (ref. 8).

A comparison between model and measurements is given in Fig. 13 for the LA Basin fruit measurements discussed above in connection with Fig. 6. These are circular flights in the Long Beach area. The fruit model predictions in Fig. 13 are based on the average of the four LA measurements plotted in Fig. 12.

The comparison indicates that f = 75/sec is a much better assignment than 150/sec, and that with this assignment, the agreement is favorable in both absolute value and power distribution.

A relatively minor departure between model and measurement is seen (in Fig. 13) in the vicinity of -65 dBm receiver threshold. A possible explanation for this concerns the traffic distribution at short range. In Fig. 12, N(R) was centered at the location of peak traffic density, whereas the fruit measurements were performed generally in the Long Beach area, but not necessarily right at the location of the density peak. An adjustment for this difference would be to replace the N(R) characteristic taken from Fig. 12 with a uniform-in-area characteristic, $N(R) \propto R^2$, for the regions near the aircraft, and for regions far from the aircraft to leave N(R) unchanged. This change has been made for ranges within 20 nmi, producing the results shown as a dotted line in Fig. 13. With this modification, there is a close agreement between model and measurement.

Another form of model vs. measurement comparison is shown in Fig. 14. Here fruit rates are given as a function of aircraft density for a fixed receiver threshold (the nominal BCAS value). Data points shown are from measurements in the LA, Washington, Philadelphia, and Boston areas (from Figs. 2,5,6,7, and 8). These are all areas in which traffic density data is available (Fig. 12). The fruit predictions in Fig. 14 are extended into traffic densities higher than present-day values in order to represent possible future conditions. For example, in the case of the high density LA traffic model (ref. 7), in which air traffic is more dense by a factor of 5 than today's traffic, Fig. 14 predicts that airborne fruit rates would grow to about 40,000 fruit/sec.

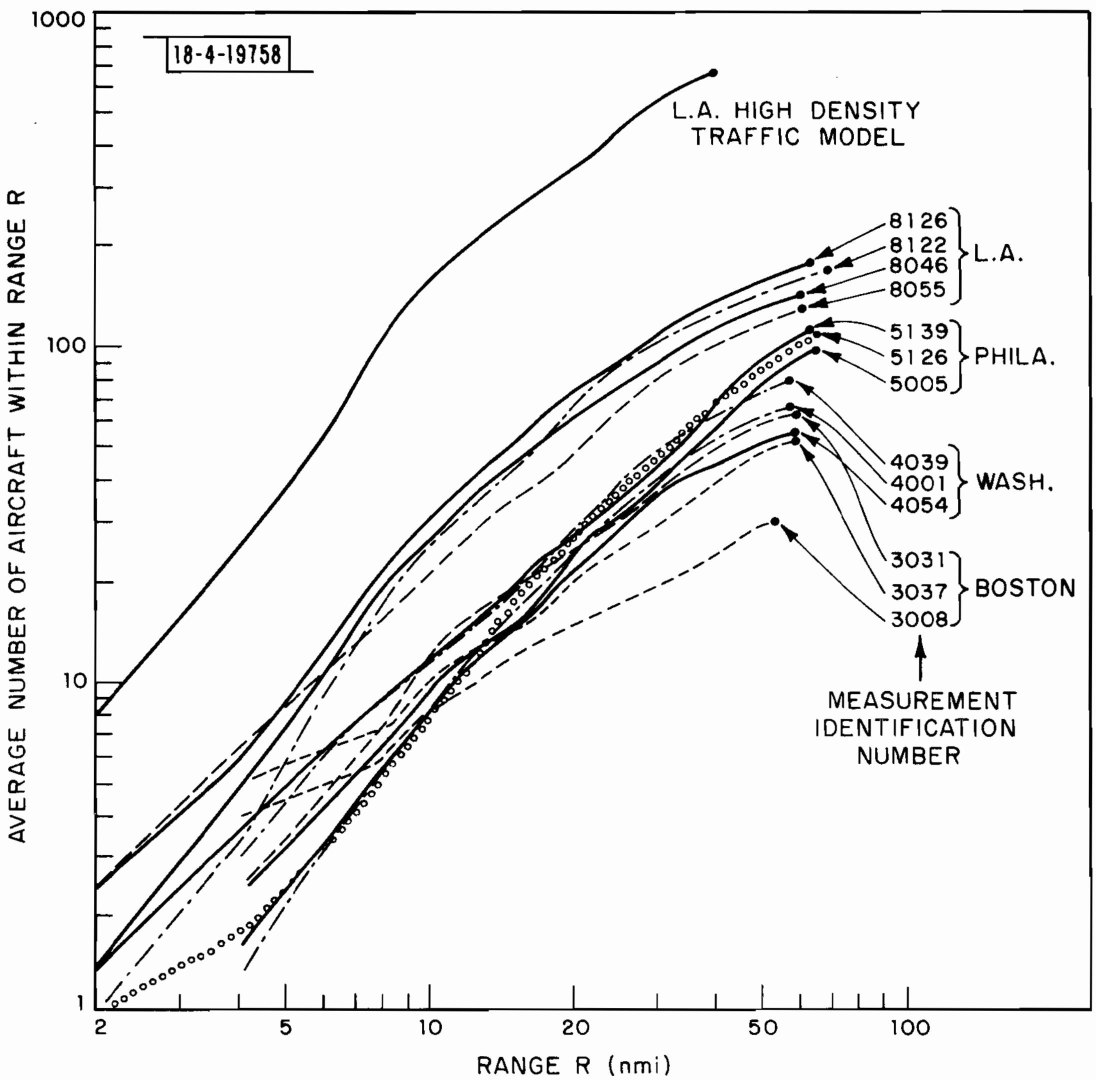


Fig.12. ATCRBS traffic distributions in range.

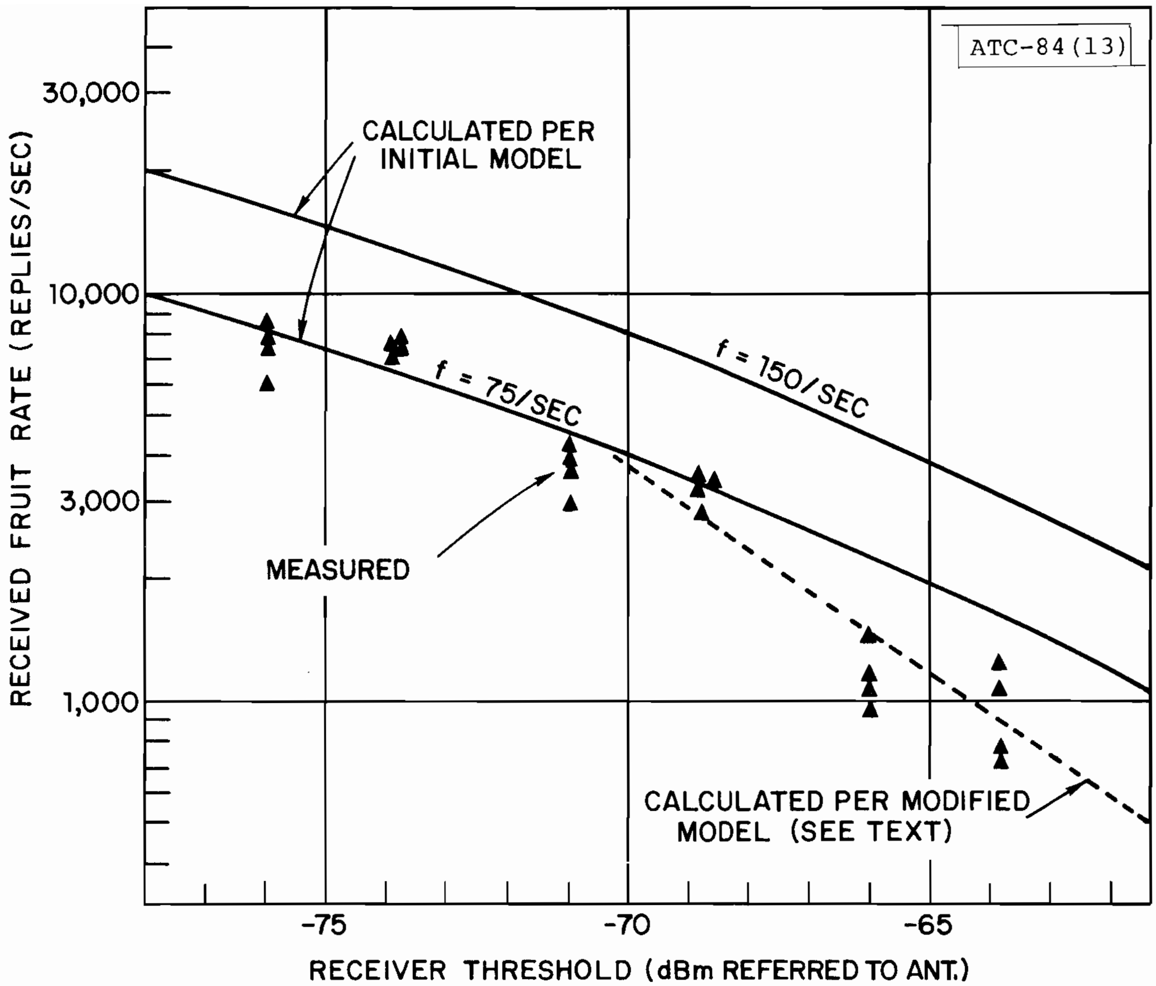


Fig. 13 Comparison between model and measurements.

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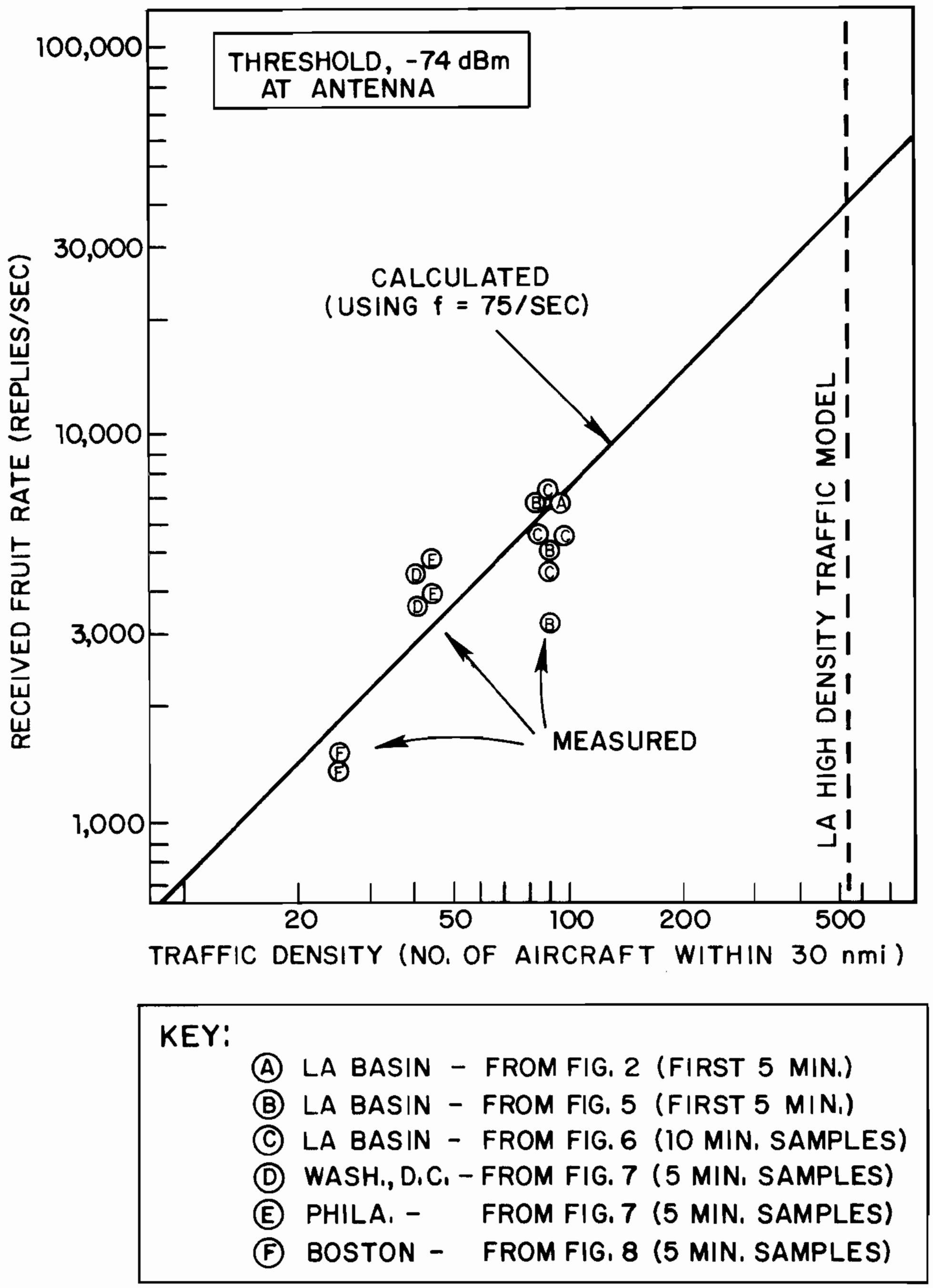


Fig. 14 Airborne fruit as a function of traffic.

## 5.0 SUMMARY

Among the airborne fruit measurements made in the LA Basin and along the East Coast from Boston to Washington, the highest observed fruit rates, approximately 10,000 replies/sec, occurred in LA. This result is consistent with the fact that ATCRBS traffic density is also the highest in LA.

A first-order fruit model was defined, allowing fruit rate predictions to be made in the form of a simple calculation. Predictions based on the model were compared with the measurements, generally showing favorable agreement in absolute fruit rate, in power distribution, and in the functional dependence on traffic density.

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