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A REVIEW OF THE NASA V-G/VGH GENERAL AVIATION PROGRAM

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16 Abstract

V-G and VGH data have been collected from a wide variety of general aviation airplanes since the inception of the NASA V-G/VGH General Aviation Program in 1962. These data have been analyzed to obtain information on the gust and maneuver loads, on the operating practices, and on the effects of different types of operations on these parameters. This paper summarizes some of the more significant findings.

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A REVIEW OF THE NASA V-G/VGH GENERAL AVIATION PROGRAM

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SUMMARY

The purpose of the NASA V-G/VGH General Aviation Program, established in 1962, was to define the gust and maneuver loads, airspeed practices, and altitude usages of general aviation airplanes and to provide a data bank of information for use by the airplane designer.

Data were collected from 134 general aviation airplanes involved in 8 types of operations. Some of the more significant results obtained from an analysis of these V-G and VGH data are presented.

INTRODUCTION

Although in-flight data were collected from commercial transport airplanes for many years, a relatively small amount of these data have been obtained from airplanes flown in general aviation operations. Accordingly, in 1962, at the request of the Federal Aviation Administration, and upon recommendation of the NASA Committee on Aircraft Operating Problems, the NASA V-G/VGH General Aviation Program was established. The purpose of the program was to define the gust and maneuver loads, airspeed practices, and altitude usages of general aviation airplanes and to provide a data bank of information for use by the airplane designer.

Since the start of the NASA V-G/VGH General Aviation Program in 1962, about 25 000 hours of VGH data and 134 000 hours of V-G data have been collected from 176 airplanes. Approximately 84 000 hours of these data from 134 airplanes have been analyzed and reported in references 1 to 6. This paper presents some of the more significant findings as related to airspeed and altitude operating practices, the relationship of gust and maneuver loads to design loads, and landing impact accelerations.

SYMBOLS

Values are given in both SI and U.S. Customary Units. The measurements and calculations were made in U.S. Customary Units.

a_n normal acceleration measured from 1.0g-level flight position of accelerometer trace, g units

$a_{n,LLF}$ normal acceleration corresponding to the gust or maneuver limit load acceleration measured from 1.0, g units

c wing chord, meters (feet)

g acceleration due to gravity, 9.81 m/sec^2 (32.2 ft/sec^2)

K_g gust factor, $\frac{0.88\mu_g}{5.3 + \mu_g}$

m slope of lift curve per radian

n_g gust limit load factor measured from 1.0

n_m maneuver limit load factor measured from 1.0

S wing area, m^2 (ft^2)

U_{de} derived gust velocity, $\frac{2Wa_n}{K_g \rho_o V_e m S}$, m/sec (ft/sec)

V_C design cruising speed, knots

V_D design dive speed, knots

V_e equivalent airspeed, knots

V_{NE} never-exceed speed, knots

W airplane weight, N (lb)

μ_g airplane mass ratio, $\frac{2W}{m \rho c g S}$

ρ atmospheric density, kg/m^3 (slugs/ft^3)

ρ_o atmospheric density at sea level, kg/m^3 (slugs/ft^3)

INSTRUMENTATION

The NASA VGH and V-G recorders with which the data were obtained are shown in figures 1 and 2, respectively. The VGH recorder provides a time-history record of the indicated airspeed, pressure altitude, and normal acceleration at the center of gravity of the instrumented airplanes. The V-G recorder provides envelope-type information of the maximum in-flight accelerations and their corresponding airspeeds. The VGH and the V-G recorders are described in references 7 and 8. A sample VGH record is shown in figure 3, and a sample V-G record is shown in figure 4.

PROGRAM DESCRIPTION

In order that a representative sample of general aviation operations could be obtained, eight types of operations were covered in the data collection program. These eight operations are: twin-engine executive, single-engine executive, personal, instructional, commercial survey, aerobatic, aerial application, and commuter. Generally, three different airplane types were selected as being typical of a given operation. The goal was to instrument 4 airplanes of each of these given types, 1 with a VGH recorder and 3 with V-G recorders, for a total of 12 instrumented airplanes in each operation. Typical uses of the airplanes in each operation are as follows:

Twin- and single-engine executive:

Charter flight – cargo and personnel
Business flight – company and individual
Instrument check flight – training for instrument card
Instructional flight – check-out for larger airplane

Personal:

Flying club owned – airplane flown by 3 to 21 members; used for pleasure, instruction, or business flying
Individually owned – used for pleasure and business flying
Company owned – airplane rented to individual for business or pleasure flying; also airplane used as check-out for heavier airplane

Instructional:

Training flights – airplanes owned by flying schools; used as basic trainers to obtain private license

Commercial survey:

Pipeline patrol flight – patrols flown 76 to 91 m (250 to 300 ft) above terrain to check for leaks or breaks in the pipeline

Forest-patrol flights – patrols flown 457 m (1500 ft) above terrain for fire detection. When fire is spotted, descents are made to 61 to 91 m (200 to 300 ft) to check conditions of terrain around the fire.

Pathfinder flights – flown to fire perimeter to mark drop area. Descents are made to 15 to 46 m (50 to 150 ft) above terrain to insure that turbulence is not too severe for chemical bombers during dropping run. Retardant drops are observed and effects on the fire are noted.

Aerobatic:

Noncompetitive flights – airplane flown by amateurs. Occasional aerobatics are performed, usually as individual maneuvers.

Competitive flights – airplane flown in airshows, in national and international aerobatic competition, and in practice sessions. Obligatory maneuvers, one immediately after another, are performed within a specified cube of airspace.

Aerial application:

Crop-dusting and/or spraying flights – airplane flown at heights ranging from 0.9 to 5.5 m (3 to 18 ft) above crops. Spreading runs are characterized by sharp push-over at start and hard pull-up at end of spreading runs.

Commuter:

Operational flights – normally scheduled passenger-carrying operations

Crew flights – crew training, or flights, during which structural or mechanical tests are made on the airplane

Care was taken in selecting airplanes in a particular operation to insure that the home bases were located throughout the continental United States. By selectively taking the data from different geographical locations, biasing of the data because of similar topography was eliminated.

Pertinent physical characteristics of the instrumented airplanes, identified by number, are given in table I. In addition, design and placard speeds and the incremental gust and maneuver limit load factors are also noted. All airplanes in the program were owned by individuals or companies who were personally contacted, briefed on the program, and asked to participate on a voluntary basis. Generally, for any VGH or V-G installation, an attempt was made to collect the data over at least the four seasons and for a period of 1000 hours.

RESULTS AND DISCUSSION

Program Status

The current status of the NASA V-G/VGH General Aviation Program and a listing of the data that have been reported are given in table II. The largest data samples were obtained from commercial survey, twin-engine executive, instructional, and commuter operations. Airplanes involved in these operations generally have a higher utilization rate and, therefore, are able to provide a larger sample than airplanes flown in other types of operations. The smallest data samples were taken from aerobatic, aerial application, personal, and single-engine executive operations. Airplane size, electrical power available, and, in the case of personal operations, agreement among members of the club owning the airplane as to whether the recorder installation should be allowed, were factors contributing to the smaller data-sample size for these operations.

Airspeed Practices

How airplanes are flown in their utilization is of interest not only to the designer but also to the Federal Aviation Administration, since this organization is responsible to the public for the safe design and operation of aircraft. The average airspeed for different types of airplanes flown in seven types of operations is shown in figure 5. This figure was taken from reference 4 and was modified to include maximum airspeeds recorded by each type of airplane. Maximum airspeed is shown as the base value of the highest 10-knot interval in which the airplane was flown. The highest average and maximum airspeeds were recorded by the turbojet-powered airplanes 1 and 2 and by the turboprop-powered airplanes 3 and 28. It is interesting to note that turboprop-powered airplane 26 had both average and maximum speeds lower than piston-powered airplane 5. The lowest overall average speeds within a given operation were recorded by airplanes involved in instructional operations; however, the lowest average speed for an individual airplane (60 knots) was recorded by airplane 18 flown in commercial fish-spotting operations. The largest deviation of maximum airspeed from average airspeed by an airplane in a given type of operation from other airplanes in that operation was by airplane 19 in commercial survey operations. This airplane was flown as a lead plane in forest-firefighting service. As such, the airplane preceded retardant bomber runs to mark specific drop areas and to check turbulence levels to assure safe bomber penetrations. Because of the mountainous terrain in which the operations were conducted, steep approaches, with resulting high speeds, were sometimes required to reach fire areas along canyon or ridge walls. In general, it appears that the excess of maximum speeds above average speeds for all the instrumented airplanes varied from one-quarter to one-third of the recorded speed range for the airplanes.

A more detailed description of airspeed practices is given in figure 6 which shows the percent of time flown in 10-knot speed intervals for each type of airplane in a designated type of operation. The airplane type, the size of the data sample from which the data were obtained, the design cruising speed, and the design dive speeds for sea-level conditions are also shown in each figure. The distribution of time flown in various speed intervals for airplanes within a given operation is generally similar. Time flown in lower speed intervals increases with speed up to the most frequently used speed – usually 10 to 30 knots below the design cruising speed for piston-powered airplanes – and then decreases as the design cruising speed is approached. Turbojet-powered airplanes 1 and 2 follow a similar trend except that the most frequented speeds are from 100 to 150 knots below the design cruising speed. This large difference was a result of the turbojet's flight at high altitudes, and therefore low indicated airspeeds, whereas the noted design cruising speeds are for sea-level conditions. It is interesting to note the similarity of the speed histories of airplanes 16 and 18 in commercial survey operations. Airplane 16 was flown on pipeline patrols, and airplane 18 was used for commercial fish spotting. Both flew about 85 percent of the time within a 20-knot speed band: the fish spotter on the low side, 50 to 70 knots, for endurance; and the pipeline patrol on the high side, 80 to 100 knots, to cover more distance. With the exception of one airplane in twin-engine executive operations and one airplane in personal operations, all airplanes reached or exceeded the design cruising speed. Airplanes 3, 9, 11, and 13 (twin-engine executive, single-engine executive, personal, and instructional, respectively) were flown above the design cruising speed from 6 to 19 percent of their flight time. Although the VGH data show no design dive speed V_D exceedances, the much larger data sample obtained from V-G recorders did. An analysis of these data in references 4 and 5 indicates that airplanes involved in instructional operations were the most susceptible to V_D overspeeds.

Altitude Practices

The variation of average and maximum altitude recorded by individual airplane types flown in the various operations is given in figure 7. Maximum altitude was noted as the base value of the highest 31-m (100-ft) intervals within which the airplane was flown. The highest flights, 12.5 km (41 000 ft), were recorded by turbojet airplanes 1 and 2. The next highest flights, 7 km (23 000 ft), were recorded by turboprop airplane 3. Four airplane types – airplane 11 in personal operations, airplane 16 in instructional operations, and airplanes 9 and 19 in commercial survey operations – were flown at significantly higher altitudes than the other airplanes in their particular operation. Airplane 16 was based in Denver, Colorado, and occasionally flew over the mountainous regions west of Denver, thereby requiring higher flights to clear the terrain. Airplanes 9 and 19 were based in Washington and Oregon and were involved in forest-firefighting services over the mountainous areas in the western portion of the states. The maximum altitude shown for airplane 11 was recorded during one flight in which a flying club member attempted to see how high he could fly that particular airplane. In general, the average flight altitude for all the piston-powered airplanes was below 2.14 km (7000 ft), and the maximum altitudes, except for airplane 11, did not exceed 4.58 km (15 000 ft).

The percent of time the piston- and turboprop-powered airplanes were flown in 0.61-km (2000-ft) altitude intervals is shown in figure 8. Similar data for the turbojet-powered airplanes are also shown; however, these data are given in 1.53-km (5000-ft) altitude intervals. The distribution of time flown in the various altitude intervals was similar for turbojet-powered airplanes 1 and 2. Both airplanes recorded larger percentages of time in the extreme altitude intervals and smaller percentages in the transition between the two. Turboprop airplane 3 was flown to approximately half the altitude of airplanes 1 and 2; however, about equal time was spent at all altitude intervals. A comparison was made of the percent of time flown above 3.05 km (10 000 ft) by piston-powered airplanes 4 and 5 in twin-engine executive operations and the corresponding percent of time for the airplanes in single-engine executive and personal operations. This comparison indicates that all the single-engine executive airplanes and two of the personal airplanes were flown above 3.05 km a substantially larger percentage of the flight time than the twin-engine executive airplanes (8 percent as compared to 1 percent). The reasons for this are unknown.

Airplanes involved in instructional operations spend from 88 to 98 percent of their flight time below 1.22 km (4000 ft). Airplane 16, based in Denver, Colorado, with a ground elevation of 1.61 km (5280 ft) spent 81 percent of its flight time below 2.44 km (8000 ft). Airplanes flown in commercial survey and aerial application operations are characterized by flight in a particular altitude interval for a significantly larger portion of their total flight time. Note, for example, airplanes 9, 16, 18, 23, and 24. Airplanes 9, 16, and 18 were flown on forest-fire patrol, pipeline patrol, and commercial fish spotting, respectively. Airplanes 23 and 24 were flown on crop-dusting operations. Airplane 19, a lead plane in forest firefighting, although flown primarily (45 percent of the time) at a specific altitude, was required to descend from that altitude periodically to mark drop areas for retardant bombers, to check turbulence levels for penetrations by retardant bombers, and to assess the results of retardant drops. These efforts are reflected in the percent of time flown in the 0.61- to 1.22-km (2000- to 4000-ft) and 1.22- to 1.83-km (4000- to 6000-ft) altitude intervals.

Airplanes 26 and 28 in figure 8(g) show the altitude operating practices of two commuter airlines. Airplane 26 was based in Long Beach on the west coast, and airplane 28 was based in Philadelphia on the east coast. Differences in percent of time spent in given altitude intervals for the two commuter operations can be attributed to the shorter flight duration of airplane 26, 15 minutes as compared with 30 minutes for airplane 28, and to the more mountainous terrain airplane 28 was routed over.

Overall In-Flight Loads

One of the largest inputs into the data bank of in-flight loads has been from V-G recorders. Airplane owners, when asked to participate in the program, have generally allowed installation of the recorder in their airplane because of the light weight and small size and because it does not require electrical power. Although the recorder does not give detailed information on the individual accelerations experienced by the instrumented airplane, it does indicate maximum accelerations and airspeeds and offers a convenient means to compare actual loads with design loads.

Comparisons of about 70 000 hr of V-G data with design loads in reference 4 indicated that, although the V-G signatures were normally contained within the design flight envelopes, commuter operations were the only type of operations in which the design flight envelope was not equaled or exceeded by at least one airplane in the operation. Figure 9 illustrates composite V-G signatures of some of the airplane types in which exceedances of the design flight envelope have occurred. Load factor is noted along the ordinate and indicated airspeed along the abscissa. The hatched area in the center of the figures is the V-G signature. The solid line around the V-G signatures denotes the design flight envelope based on the airplane maximum gross weight, and the dashed outline identifies the design flight envelope based on the minimum flying weight. The design cruising speed V_C and the design dive speed V_D are labeled above each composite. The listings to the right of each figure give the type of airplane the data were taken from, the number of airplanes of that type the data came from, the number of V-G records used to form the composite, and the number of flight hours represented by the composite.

Exceedances of the high speed V_D limit of the design flight envelope were recorded by at least one airplane in four of the six types of operations shown in figure 9. The most exceedances of V_D, other than by the airplanes flown in competitive aerobatics, were by airplanes flown in instructional operations. There, student pilots, because of inexperience and/or an adventurous nature, probably placed the airplane in such an attitude that recovery without excess speed was improbable. The V_D exceedance by airplane 5B was recorded on a demonstration flight when the airplane was being sold and, therefore, should not be considered typical for airplanes flown in twin-engine executive operations. The type of operation in which airplane 11 was flown, coupled with a clean aerodynamic configuration and sufficient power (as evidenced by the thickness of the V-G signature near the design dive speed), enabled this type of airplane to reach and exceed V_D. Airplane 22 was flown in competitive aerobatics and, thereby, was placed in attitudes and speed conditions from which recoveries without V_D exceedances were unlikely.

Exceedances of the load factor limits of the design flight envelope from maneuver inputs were primarily confined to airplanes flown in aerobatic operations, aerial application operations, and instructional operations. The largest exceedances of the design maneuver envelope were recorded by airplanes flown in competitive aerobatics. Here, obligatory maneuvers – that is, maneuvers performed one after another in a designated cube of air space – were rarely contained within the minimum limits of the 6g and -3g required for certification in the aerobatic category. Airplanes flown in basic flight instruction were the second most frequent violators of the design maneuver envelope. Note, for example, the V-G signature for airplane 13 in figure 9(c). The design flight envelope limits were exceeded in both the positive and negative direction at the worst possible speed parameter, V_D. Although airplanes flown in aerial application operations were not subjected to frequent maneuver accelerations in excess of the design flight envelope, the fullness of the V-G signature below V_C in figure 9(e) indicates the frequency with which maneuver loads near the design flight envelope were experienced. The extreme load factors recorded by airplane 15 in figure 9(c) occurred when the instrumented airplane crashed.

Turbulence, or gust-induced exceedances of the design flight envelope, was recorded most frequently by airplanes flown on pipeline patrol. What appear to be maneuver responses on the V-G signatures of airplanes in figure 9(d) are reported incidents of severe turbulence encounters. The most severe turbulence experience was recorded by airplane 9D, flown in the Rocky Mountain regions of Colorado, Utah, and Wyoming. Airplane 16A, flown on pipeline patrol in Texas, Oklahoma, and Kansas, although experiencing large and frequent gust loads, was not subjected to as severe a pounding as airplane 9D. Airplane 4 (fig. 9(a)), flown in twin-engine executive operations, recorded both positive and negative gust accelerations which exceeded the design flight envelope. These exceedances were also recorded in mountainous regions of the eastern and western United States. The large positive acceleration recorded by airplane 6 in figure 9(a) was reportedly experienced when the airplane encountered the wake vortex from a Boeing 727 in the landing configuration near Miami International Airport.

The variation of intensity and frequency of occurrence of gust and maneuver accelerations recorded by general aviation airplanes flown in different types of operations have been studied and noted for various sample sizes since samples large enough to be analyzed have been acquired in this program. Results of these studies are noted in references 1 to 6.

Gust Acceleration Fractions

Figure 10 illustrates the gust acceleration experience that may be expected by airplanes flown in seven types of operations. In order to provide a common basis for comparison of the gust accelerations, incremental accelerations recorded by each airplane were divided by that airplane's incremental gust limit load factor at the design cruising speed. This ratio, identified as the acceleration fraction, has been used in past VGH analyses and is useful in combining and comparing data samples from airplanes having different limit load factors. Gust acceleration fractions are noted along the abscissa, and the cumulative frequency of occurrence of the acceleration fractions is given along the ordinate. The hatched bands in the figure, obtained from unpublished transport VGH data, are shown to compare the general aviation airplane gust acceleration fraction experience with that for three types of short- to medium-haul jet transports.

The general impression given by figure 10 is that the distribution of positive and negative gust acceleration fractions is symmetrical; negative distributions are nearly mirror images of positive distributions. It is also apparent that the frequency of occurrence of gust acceleration fractions of a given value for the general aviation airplanes covers a much wider range than for the short-haul jet transports. The broad band for the general aviation airplanes, bounded on the high side by airplanes flown in commercial survey operations and on the low side by turbojet-powered airplanes flown in twin-engine executive operations, is typical of the varied gust acceleration experience of general aviation airplanes. Differences between the frequency of occurrence of a given value of gust acceleration fraction varied by as much as 3 orders of magnitude between turbojet airplanes flown in twin-engine executive operations and piston airplanes flown in commercial survey operations. The most severe gust alleviation fractions, recorded by airplanes flown in instructional and twin-engine executive operations over mountainous terrain, were more than twice the magnitude of the most severe gust acceleration fractions experienced by short-haul jet transports.

Derived Gust Velocities

The derived gust velocity U_{de} recorded per nautical mile of flight in 0.61-km (2000-ft) altitude intervals for the combined data sample of piston-powered airplanes is shown in figure 11. Derived gust velocity in meters per second is given along the abscissa, and the cumulative frequency of occurrence of the gust velocity per nautical mile of flight is shown along the ordinate. Symbols identify the altitude interval, the hours, and the nautical miles flown in the altitude interval.

Figure 11 shows that the frequency of occurrence per nautical mile of derived gust velocities generally decreases with an increase in altitude for gust velocities below about 7.32 m/sec (24 ft/sec). Above this gust velocity, there appears to be a gradual reversal, with the frequency of occurrence of a given gust velocity increasing as altitude increases. Figure 11 also indicates that the largest values of U_{de} occur in the lowest altitude ranges. It should be pointed out that 98.4 percent (11 136 hr) of the data sample for figure 11 was obtained below 3.7 km (12 000 ft), and only 1.6 percent (188.4 hr) was obtained for the sample above 3.7 km. In general, the most severe derived gust velocities, from the standpoint of magnitude and frequency of occurrence, occur at altitudes below 3.05 km (10 000 ft).

The cumulative frequency of occurrence of the derived gust velocity per nautical mile of flight within specified altitude intervals for airplanes flown in seven types of operations is shown in figure 12. Data from turbojet-powered airplanes flown in twin-engine executive operations were separated for the data from propeller-driven airplanes flown in the same operation because of the large differences in flight altitudes utilized by the different airplanes. Altitude bands of 1.53 km (5000 ft) were used in presenting the turbojet-powered-airplane data, and bands of 0.61 km (2000 ft) were used for the prop-driven-airplane data.

The broadest bands of data, that is, data having the widest range of frequency of occurrence for a given gust velocity, were recorded by both the turbojet and the prop-driven airplanes in twin-engine executive operations and by airplanes flown in instructional operations. Airplanes flown in single-engine executive, personal, commercial survey, and commuter operations experienced given gust velocities in a relatively narrow frequency of occurrence range, within 1 order of magnitude. The highest gust velocities, 20.7 m/sec (68 ft/sec) and 18.3 m/sec (60 ft/sec), were recorded in the 0.61-km (2000-ft) to 1.22-km (4000-ft) and the 1.83-km (6000-ft) to 2.44-km (8000-ft) altitude bands, respectively, by airplanes flown in commercial survey operations. It should be noted that airplanes flown in commercial survey operations experienced given gust velocities about an order of magnitude more frequently than airplanes flown in other types of operations. Airplanes flown in aerial application (crop-dusting and/or spraying) operations encountered gusts relatively infrequently because of the nature of the operation. In order to avoid contamination of crops in fields adjacent to the field being sprayed, it was frequently necessary to conduct these operations in relatively calm air. Airplane 23 was flown almost entirely in night operations to take advantage of the "heavier" and "quieter" night air.

Manuever Acceleration Fractions

Figure 13 shows the cumulative frequency of occurrence of maneuver acceleration fractions per nautical mile of flight for airplanes flown in seven types of operations. Bands indicating the limits of maneuver acceleration fractions recorded by three different types of turbojet-powered commercial transports flown over short- to medium-haul routes are also shown for comparative purposes. As discussed in the section "Gust Acceleration Fractions," the use of acceleration fractions allows the data to be normalized so that valid comparisons can be made between airplanes having different design limit load factors.

Although the distribution of gust acceleration fractions was practically symmetrical, the distribution of maneuver acceleration fractions was biased, as would be expected, toward the positive side. The most frequent occurrence of maneuver acceleration fractions between 0.8 and -0.6 was recorded by airplanes used in aerial application operations. The severity of this type of operation is illustrated in figure 13 which shows that the positive acceleration fractions recorded by these airplanes are, for a given value, experienced from a low of 6 to a high of more than 100 times more frequently than airplanes flown in the next more severe operations – commercial survey and instructional. The severity of the aerial application operation is further emphasized by noting that negative maneuver acceleration fractions up to -0.4 are experienced more frequently than positive maneuver acceleration fractions recorded by airplanes flown in commercial survey operations. Airplanes in two of the operations, twin-engine executive (jet) and instructional, reached or exceeded the positive design maneuver limit load factor. The exceedance by the twin-engine executive jet airplanes occurred during a demonstration flight and should not be considered to be representative of twin-engine executive operations. The exceedance by airplanes flown in instructional operations, however, was no surprise, since airplanes flown in this category are piloted by individuals lacking both experience and judgment. Statistical results reported in reference 5 indicated that for given samples of 10 000 and 20 000 hr, airplanes flown in instructional operations exhibited the highest probability of reaching the design maneuver limit and ultimate loads for the seven types of operations compared. The maneuver-acceleration-fraction experiences for airplanes flown in twin-engine executive (jet) operations below 0.7 and for twin-engine executive (prop), single-engine executive, personal, and commuter operations were generally similar; that is, each had a frequency of occurrence for a given acceleration fraction within about 1 order of magnitude. It should also be noted from figure 13 that airplanes in general aviation operations were flown closer to the maneuver limit load factor than short-haul jet transports and, for given acceleration fractions greater than 0.3 and -0.2, experienced given maneuver acceleration fractions more often per mile of flight.

Additional maneuver data covered in reference 6, but not included in figure 13, were obtained from airplanes used as retardant bombers in forest-firefighting operations. These airplanes, because of the necessity for reaching fires in relatively inaccessible areas, recorded rates of descent of up to 2745 m/min (9000 ft/min) and equaled or exceeded the design maneuver limit load factor, based on the maximum gross weight, in 10 percent of the pull-outs after release of the retardant.

Comparison of Gust and Maneuver Acceleration Fractions

Reference 2, one of the first papers covering results obtained from the NASA V-G/VGH General Aviation Program, compared the gust loading experience with the maneuver loading experience for airplanes flown in different types of operations. At the time of the report, data samples were meager, and rather inconclusive results were drawn. Since the data sample currently available for analysis is considerably larger, figure 14 was prepared to compare the cumulative frequency of occurrence per nautical mile of flight of positive and negative gust and maneuver acceleration fractions from airplanes flown in each of seven types of operations. Because of the different flight environments experienced by propeller- and turbojet-driven airplanes in twin-engine executive operations, data for these airplanes are presented separately in figures 14(a) and 14(b), respectively.

As mentioned in the preceding section on maneuver acceleration fractions, the data in figure 14(b), obtained from five turbojet airplanes flown in twin-engine executive operations, are heavily weighted by data from three of these airplanes used as flight demonstrators, which are subjected to more frequent and larger than normal maneuver accelerations. It is therefore believed that figure 14(b) is more representative of flight loads that would be expected of airplanes used for sales demonstrators than for twin-engine executive operations. A comparison of gust with maneuver loadings for airplanes in the seven types of operations shows that gust loads are more severe for airplanes flown in twin-engine executive (prop) and single-engine executive operations. Commuter operations (fig. 14(h)) indicate that gust loads are more severe for acceleration fractions up to 0.50, but the maneuver inputs are more severe above this value. Airplanes flown in instructional and aerial application operations (figs. 14(e) and 14(g)) show that maneuver loads are more severe; however, for the instructional operations, although the maneuver loads are more severe from a standpoint of frequency of occurrence, the largest acceleration fraction resulted from a gust load. Commercial survey operations (fig. 14(f)) indicate little difference between gust and maneuver loads, except that below an acceleration fraction of 0.30, gust loads are experienced more often. Personal operations (fig. 14(d)) also show little difference between the severity of gust and maneuver loads. Gust inputs are predominant up to an acceleration fraction of 0.25, and above this value, maneuver inputs are more predominant. All operations, except aerial application, show negative gust loadings to be more severe than negative maneuver loadings.

Comparison of Landing Impact Accelerations

Table III was taken from reference 5 to illustrate the relative severity of landing impact accelerations for the seven operations. The table shows the predicted number of landings required to reach or exceed the minimum design load factor of 2.67 specified in FAR 23.473(g) (ref. 9). The acceleration value used in the determination was the initial positive landing impact acceleration, which was not necessarily the highest acceleration recorded during landing touchdown.

Airplanes flown in aerial application operations were subjected to the most severe landing acceleration experience of all the general aviation operations. One explanation is that the crop-dusting airplanes were flown from extremely rough surfaces – fields, roads, or dirt strips adjacent to work areas – compared to the prepared surfaces from which airplanes were flown in the other types of operations. Another factor that may contribute to the more severe landing accelerations is the high ratio of night landings made by the airplanes involved in the data sample. The least severe landing impacts were recorded by airplanes flown in commuter operations. Pilots for these airplanes spend almost as much time in the landing pattern as they do en route and, therefore, develop above average landing skills. As expected, airplanes flown in instructional operations also experienced severe landing impacts because of the predominance of landings made by student pilots. Airplanes in the remaining operations fell somewhere between the severe experience for aerial application and the relatively light experience for the commuter airplanes. The similarity between the number of landings required to reach the minimum design load factor for airplanes flown in single-engine executive and personal operations was unexpected. It was believed that the single-engine executive airplane landing experiences should have been less severe than those for the airplanes in personal operations, supposedly because the executive airplane pilots were more experienced. The mild landing impact acceleration experiences for the twin-engine executive airplanes were, it is believed, a result of the more sophisticated landing-gear system on these airplanes, landings on smooth prepared surfaces, and pilot experience.

CONCLUSIONS

Results obtained from an analysis of V-G and VGH data collected from 134 general aviation airplanes involved in 8 types of operation suggest the following conclusions:

1. The excess of maximum airspeed above average airspeed varies from one-quarter to one-third of the recorded speed range for the airplanes.

2. The majority of general aviation airplanes reach or exceed the design cruising speed. Competitive aerobatic and instructional airplanes exceed the design dive speed more frequently than airplanes in any other type of operations.

3. Average flight altitudes for piston-powered airplanes are below 2.14 km (7000 ft), and maximum recorded altitudes do not exceed 4.58 km (15 000 ft). Instructional airplanes are flown under 1.22 km (4000 ft) from 88 to 98 percent of their flight time. Airplanes in commercial survey and aerial application operations are characterized by flight in a relatively narrow altitude band for a significant portion of their flight time.

4. The most severe overall in-flight loads are recorded by airplanes flown in competitive aerobatics and in pipeline patrol operations over mountainous regions.

5. The frequency of occurrence of given gust accelerations varies by as much as 3 orders of magnitude between airplanes flown in different operations. The most severe gust acceleration fractions recorded by general aviation airplanes were more than twice the magnitude of the most severe gust acceleration fractions experienced by short-haul jet transport airplanes.

6. The most severe derived gust velocities, from the standpoint of magnitude and frequency of occurrence, occur at altitudes below 3.05 km (10 000 ft).

7. From a repeated-loads standpoint the most severe maneuver accelerations are experienced by airplanes flown in aerial application operations. The largest maneuver accelerations are experienced by instructional airplanes.

8. General aviation airplanes are flown closer to the design maneuver limit load factor than short-haul jet transport airplanes; and for acceleration fractions greater than 0.3 and -0.2, they experience given maneuver acceleration fractions more often per mile of flight. Airplanes flown as retardant bombers in forest-firefighting operations equal or exceed a maneuver acceleration fraction of one in a significant percentage of pull-ups after release of the retardant.

9. Considering the relative severity of gust and maneuver loads, gust loads are more severe for twin-engine executive and single-engine executive operations, and maneuver loads are more severe for aerial application and instructional operations. Little difference exists between the severity of gust or maneuver loads for commercial survey airplanes. The degree of severity shifts from gust to maneuver for airplanes in personal and commuter operations as the acceleration fraction increases.

10. The types of operations, in increasing order of the predicted number of landings required to reach or exceed the minimum design load factor, are: aerial application, instructional, single-engine executive, personal, commercial survey, twin-engine executive, and commuter.

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Hampton, Va. 23665
December 1, 1975

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TABLE I. - CHARACTERISTICS OF INSTRUMENTED AIRPLANES

Characteristic	Twin-engine executive operation for airplane type –							
	1	2	3	4	5A	5B	5C	6
Maximum gross weight:								
kN	117.7	55.6	40.0	21.4	21.5	22.7	22.2	30.2
lb	26 455	12 500	9000	4800	4830	5100	4990	6800
Wing span:								
m	16.3	11.5	14.0	11.3	11.0	11.2	11.2	12.1
ft	53.5	37.6	45.9	37.0	36.0	36.9	36.9	39.8
Wing area:								
m^2	41.0	21.5	26.0	19.2	16.3	16.3	16.3	18.6
ft^2	441	231.8	279.7	207	175	175	175	200
Type of propulsion	Turbojet	Turbojet	Turboprop	Piston	Piston	Piston	Piston	Piston
V_C at sea level, knots	388	350	208	172	182	182	182	200
V_{NE} at sea level, knots	[a]437	[a]358	234	216	215	223	219	236
V_D at sea level, knots	485	400	260	240	239	248	243	262
Δn_m at V_C	1.50	3.40	2.70	2.80	2.80	2.80	2.80	2.60
$-\Delta n_m$ at V_C	2.00	2.76	2.68	2.52	2.52	2.52	2.52	2.44
$\pm\Delta n_g$ at V_C	3.40	2.44	2.10	2.10	1.97	1.84	1.91	1.93

[a]Maximum operating speed.

TABLE I. - Continued

Characteristic	Single-engine executive operation for airplane type –												
	7A	7B	8A	8B	8C	8D	8E	8F	8G	9A	9B	9C	9D
Maximum gross weight:													
kN	12.9	12.9	11.8	12.3	12.3	13.1	13.9	15.1	14.7	11.3	12.5	11.8	12.5
lb	2900	2900	2650	2775	2775	2950	3125	3400	3300	2550	2800	2650	2800
Wing span:													
m	11.0	11.0	10.0	10.0	10.0	10.0	10.2	10.2	10.2	11.0	11.0	11.0	11.0
ft	36.0	36.0	32.8	32.8	32.8	32.8	33.5	33.5	33.5	36.0	36.0	36.0	36.2
Wing area:													
m^2	16.5	16.5	16.5	16.5	16.5	16.5	16.8	16.8	16.8	16.2	16.2	16.2	16.2
ft^2	178	178	177.6	177.6	177.6	177.6	181	181	181	174	174	174	174
Type of propulsion . . .	Piston	Piston	Piston	Piston	Piston	Piston	Piston	Piston	Piston	Piston	Piston	Piston	Piston
V_C at sea level, knots	156	156	139	152	152	174	161	165	165	139	139	139	139
V_{NE} at sea level, knots	197	197	175	175	182	195	195	195	195	160	167	162	167
V_D at sea level, knots	219	219	217	217	201	217	217	217	217	177	186	180	186
Δn_m at V_C	2.80	2.80	3.40	3.40	3.40	3.40	3.40	3.40	3.40	2.80	2.80	2.80	2.80
$-\Delta n_m$ at V_C	2.52	2.52	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.52	2.52	2.52	2.52
$\pm\Delta n_g$ at V_C	2.65	2.45	2.40	2.58	2.88	2.75	2.43	2.37	2.38	2.50	2.33	2.33	2.50

TABLE I. - Continued

Characteristic	Personal operation for airplane type –					Instructional operation for airplane type –						
	10A	10B	11	12A	12B	13	14	15	16A	16B	16C	17
Maximum gross weight:												
kN	9.8	10.2	11.5	9.8	10.7	6.7	7.3	8.7	6.7	7.1	7.1	10.0
lb	2200	2300	2575	2200	2400	1500	1650	1950	1500	1600	1600	2250
Wing span:												
m	11.0	11.0	10.7	9.1	9.1	10.7	9.1	9.1	10.2	10.2	10.0	10.7
ft	36.0	36.2	35.0	30.0	30.0	35.2	30.0	30.0	33.4	33.6	32.7	35.0
Wing area:												
m^2	16.2	16.2	15.5	14.9	14.9	15.8	13.7	14.9	14.9	14.9	14.6	16.8
ft^2	174	174	167	160	160	170	147	160	160	160	157	181
Type of propulsion	Piston	Piston	Piston	Piston	Piston	Piston	Piston	Piston	Piston	Piston	Piston	Piston
V_C at sea level, knots . . .	122	126	130	122	122	87	96	122	104	104	104	117
V_{NE} at sea level, knots . . .	148	158	164	148	148	117	129	149	137	141	141	147
V_D at sea level, knots . . .	165	175	182	165	165	130	143	164	152	156	156	164
Δn_m at V_C	2.80	2.80	2.80	2.80	2.80	3.52	3.40	2.80	3.40	3.40	3.40	2.60
$-\Delta n_m$ at V_C	2.52	2.52	2.52	2.52	2.52	2.20	2.76	2.52	2.76	2.76	2.76	2.52
$\pm\Delta n_g$ at V_C	2.40	2.77	2.42	2.30	2.30	2.38	2.00	2.30	2.59	2.46	2.40	2.46

TABLE I.- Continued

Characteristic	Commerical survey operation for airplane type –							Aerobatic operation for airplane type –			
	9A	9B	9D	16A	16C	18	19	20	21	21A	22
Maximum gross weight:											
kN	11.3	12.5	12.5	6.7	7.1	6.7	13.1	7.3	8.9	8.9	5.1
lb	2550	2800	2800	1500	1600	1500	2950	1650	2000	2000	1150
Wing span:											
m	11.0	11.0	11.0	10.2	10.0	10.7	10.0	9.8	9.5	9.5	Upper 5.3 Lower 5.2
ft	36.0	36.0	36.2	33.4	32.7	35.2	32.8	32.0	31.3	31.3	Upper 17.3 Lower 16.8
Wing area:											
m^2	16.2	16.2	16.2	14.9	14.6	16.6	16.5	15.7	16.0	16.0	Upper 4.6 Lower 4.5
ft^2	174	174	174	160	157	178.5	177.6	169	172	172	Upper 50.0 Lower 48.4
Type of propulsion	Piston	Piston	Piston	Piston	Piston	Piston	Piston	Piston	Piston	Piston	Piston
V_C at sea level, knots . . .	139	139	139	104	104	96	152	114	109	109	126
V_{NE} at sea level, knots . . .	160	167	167	137	141	129	219	226	174	174	176
V_D at sea level, knots . . .	177	186	186	152	156	143	243	251	200	200	195
Δn_m at V_C	2.80	2.80	2.80	3.40	3.40	3.40	5.00	5.00	5.00	5.00	5.00
$-\Delta n_m$ at V_C	2.52	2.52	2.52	2.76	2.76	2.76	4.00	6.00	4.00	4.00	4.00
$\pm\Delta n_g$ at V_C	2.50	2.33	2.50	2.59	2.40	2.59	2.26	3.10	-----	-----	3.07

TABLE I. - Concluded

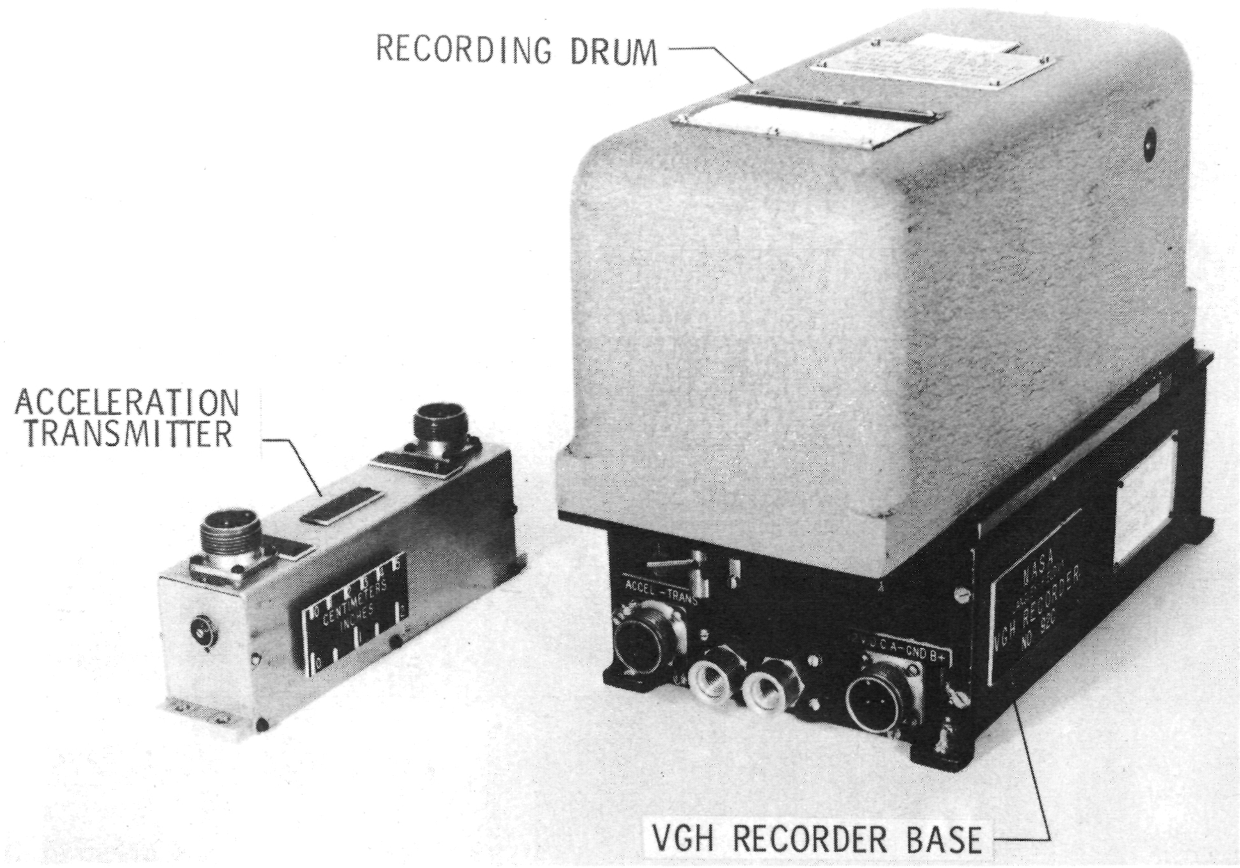
Characteristic	Aerial application operation for airplane type –			Commuter operation for airplane type –		
	23	24	25	26	27	28
Maximum gross weight:						
kN	26.7	12.9	20.0	51.6	37.8	46.3
lb	6000	2900	4500	11 600	8500	10 400
Wing span:						
m	13.5	11.0	Upper 10.9 Lower 10.4	19.8	15.3	14.0
ft	44.3	36.2	Upper 35.7 Lower 34.0	65.0	50.3	45.9
Wing area:						
m^2	30.3	17.0	Upper 15.6 Lower 14.9	39.0	27.3	26.0
ft^2	326.6	183.0	Upper 168.0 Lower 160.0	420.0	293.9	279.7
Type of propulsion	Piston	Piston	Piston	Turboprop	Piston	Turboprop
V_C at sea level, knots	117	108	87	164	178	226
V_{NE} at sea level, knots . . .	148	135	128	202	234	226
V_D at sea level, knots	164	151	142	225	260	282
Δn_m at V_C	2.80	2.80	3.20	2.21	2.70	2.29
$-\Delta n_m$ at V_C	2.90	2.52	2.00	2.50	2.60	2.31
$\pm\Delta n_g$ at V_C	1.78	1.83	1.85	2.35	1.95	1.95

TABLE II. - STATUS OF V-G/VGH GENERAL AVIATION PROGRAM

Operation	Collected				Reported			
	VGH data		V-G data		VGH data		V-G data	
	Airplanes	Hours	Airplanes	Hours	Airplanes	Hours	Airplanes	Hours
Twin-engine executive	11	6 504	20	21 520	9	3 909	18	13 622
Single-engine executive	9	2 092	16	12 878	8	1 182	15	7 808
Personal	9	1 976	23	13 496	6	712	16	5 283
Instructional	9	4 731	23	19 317	6	2 759	17	9 499
Commercial survey	10	3 827	16	41 165	6	3 334	14	23 585
Aerobatic	1	12	5	721	1	12	5	406
Aerial application	5	1 200	9	4 780	2	487	7	1 637
Commuter	2	4 836	8	20 645	2	940	5	4 358
Total	56	25 178	120	134 522	40	13 335	97	66 198

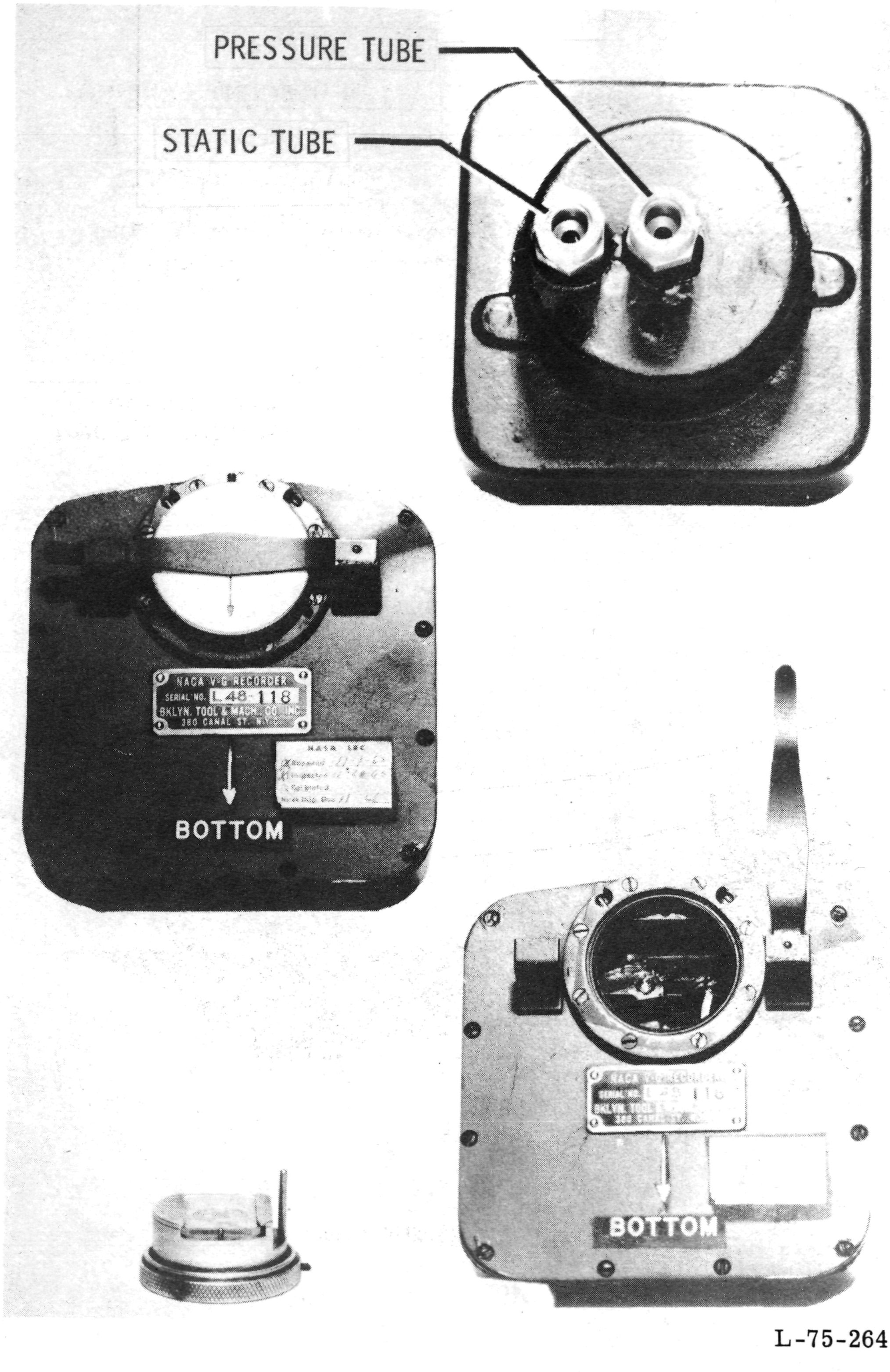
TABLE III. - PREDICTIONS OF LANDINGS REQUIRED TO REACH OR EXCEED THE MINIMUM DESIGN LOAD FACTOR OF 2.67

Operational category	Landings required
Aerial application	860
Instructional	3 393
Single-engine executive	19 295
Personal	19 554
Commercial survey	81 321
Twin-engine executive	269 297
Commuter	1 507 121



L-75-263

Figure 1.- NASA VGH recorder.



L-75-264

Figure 2.- V-G recorder.

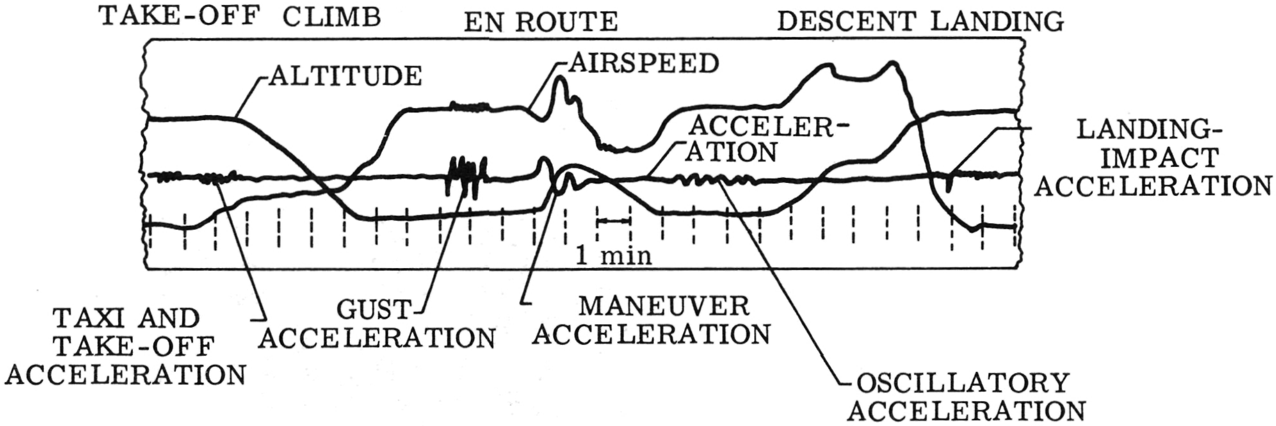


Figure 3.- Illustrative VGH record.

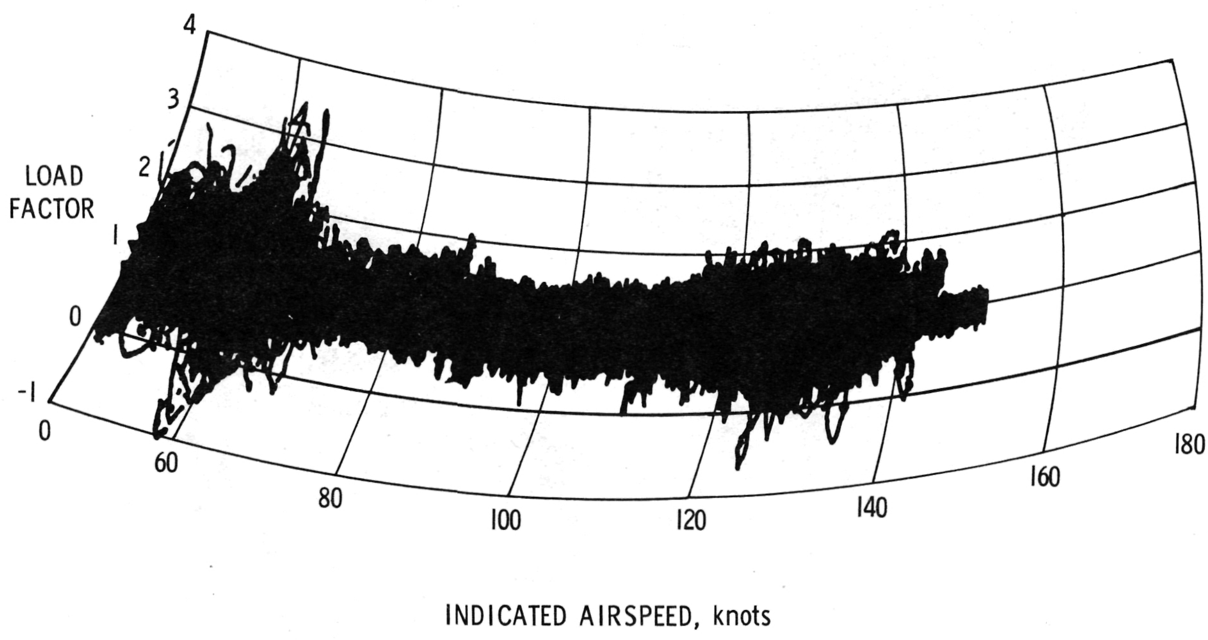


Figure 4.- Example of V-G record.

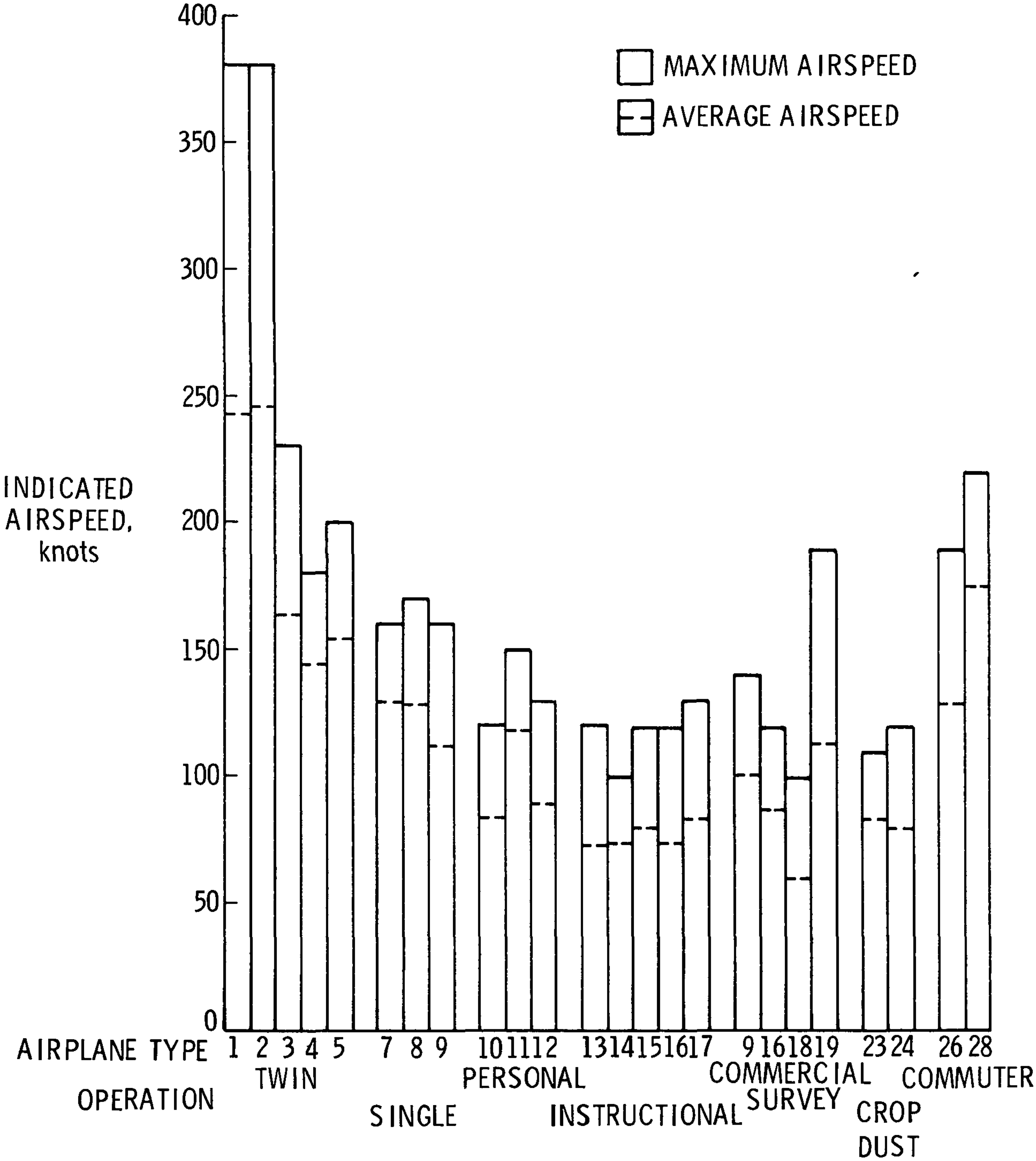
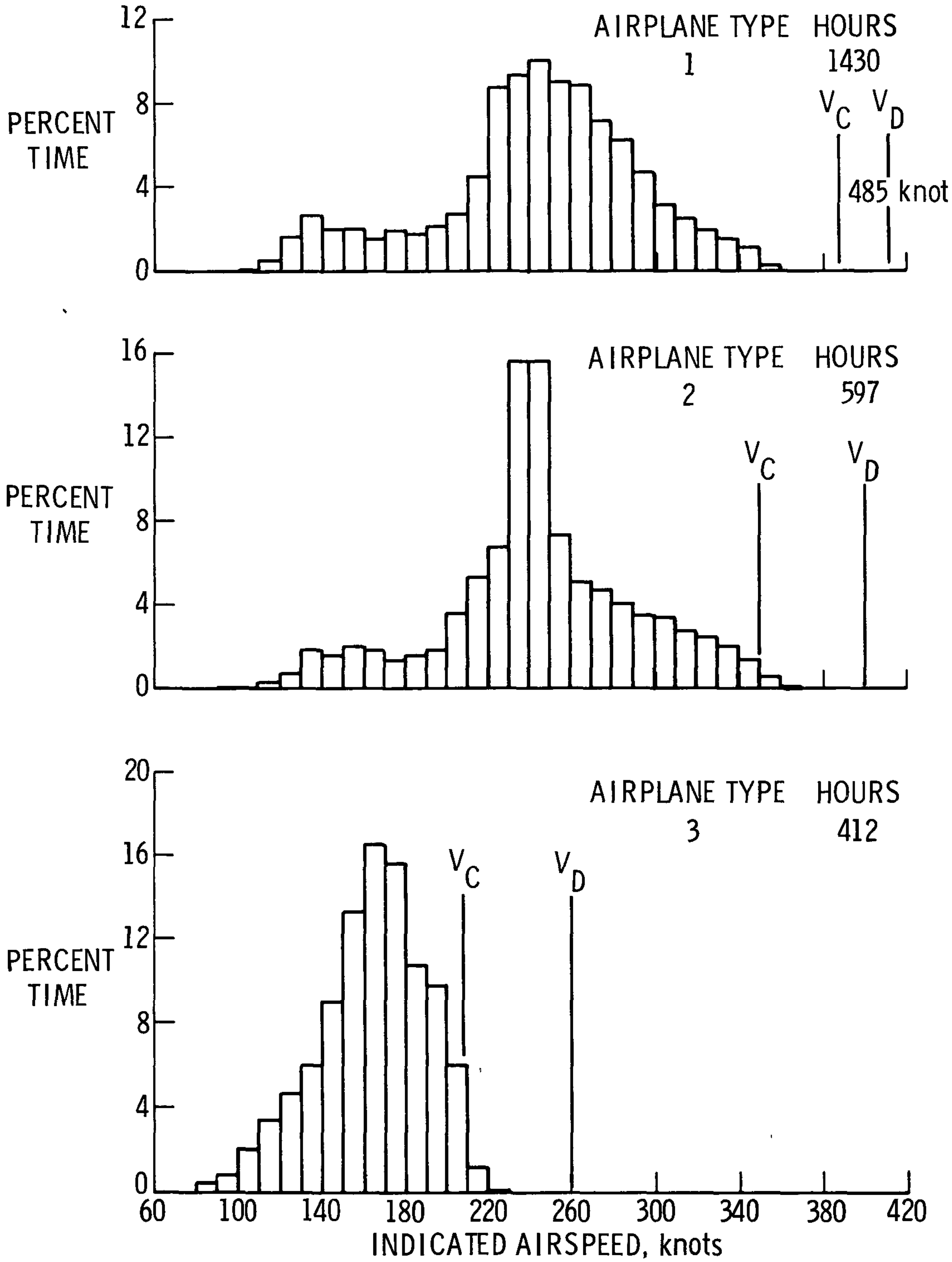
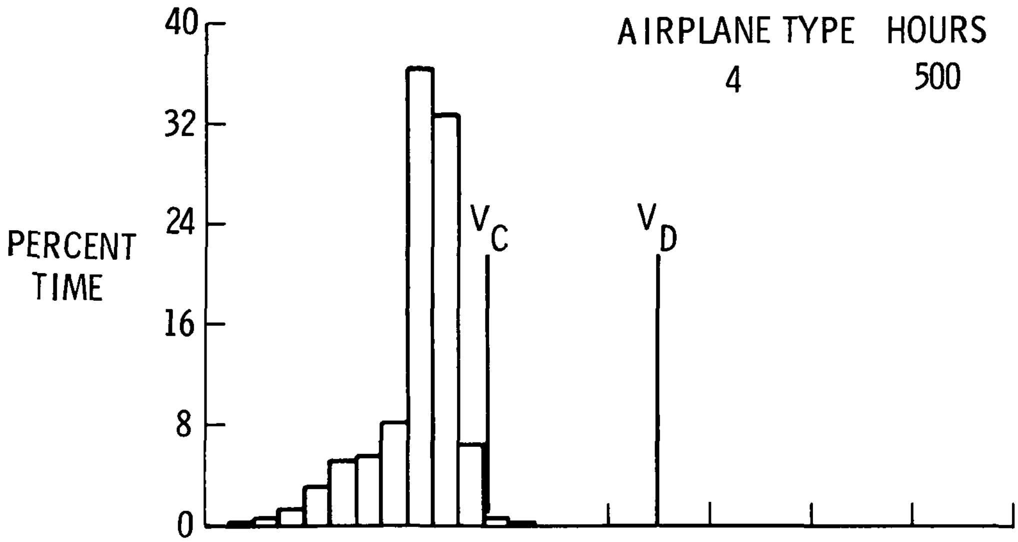


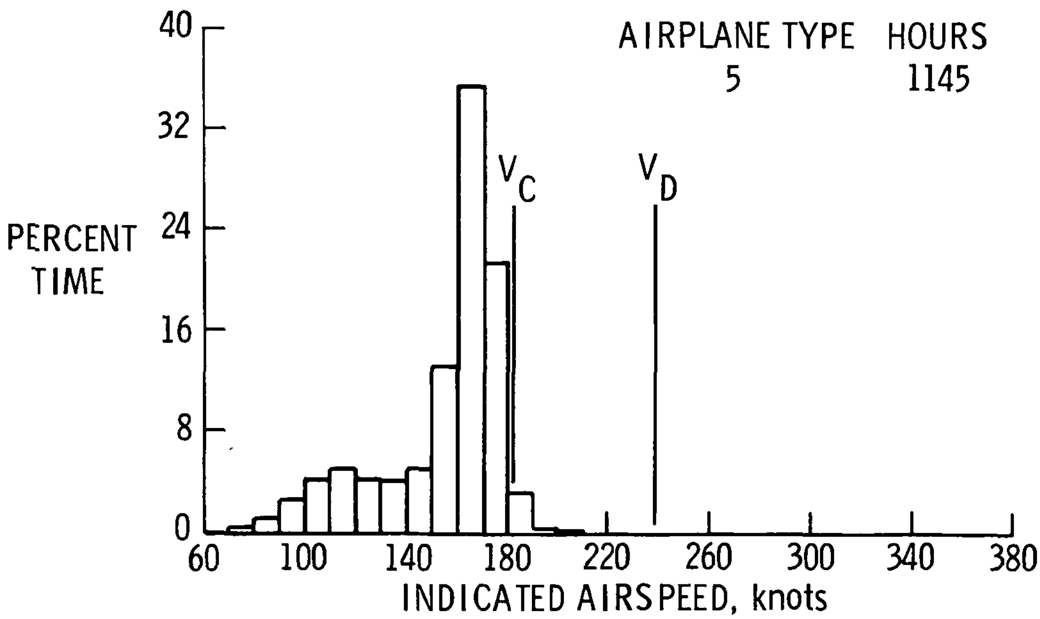
Figure 5.- Histogram of average and maximum airspeeds recorded by airplanes in various types of operations.



(a) Twin-engine executive.

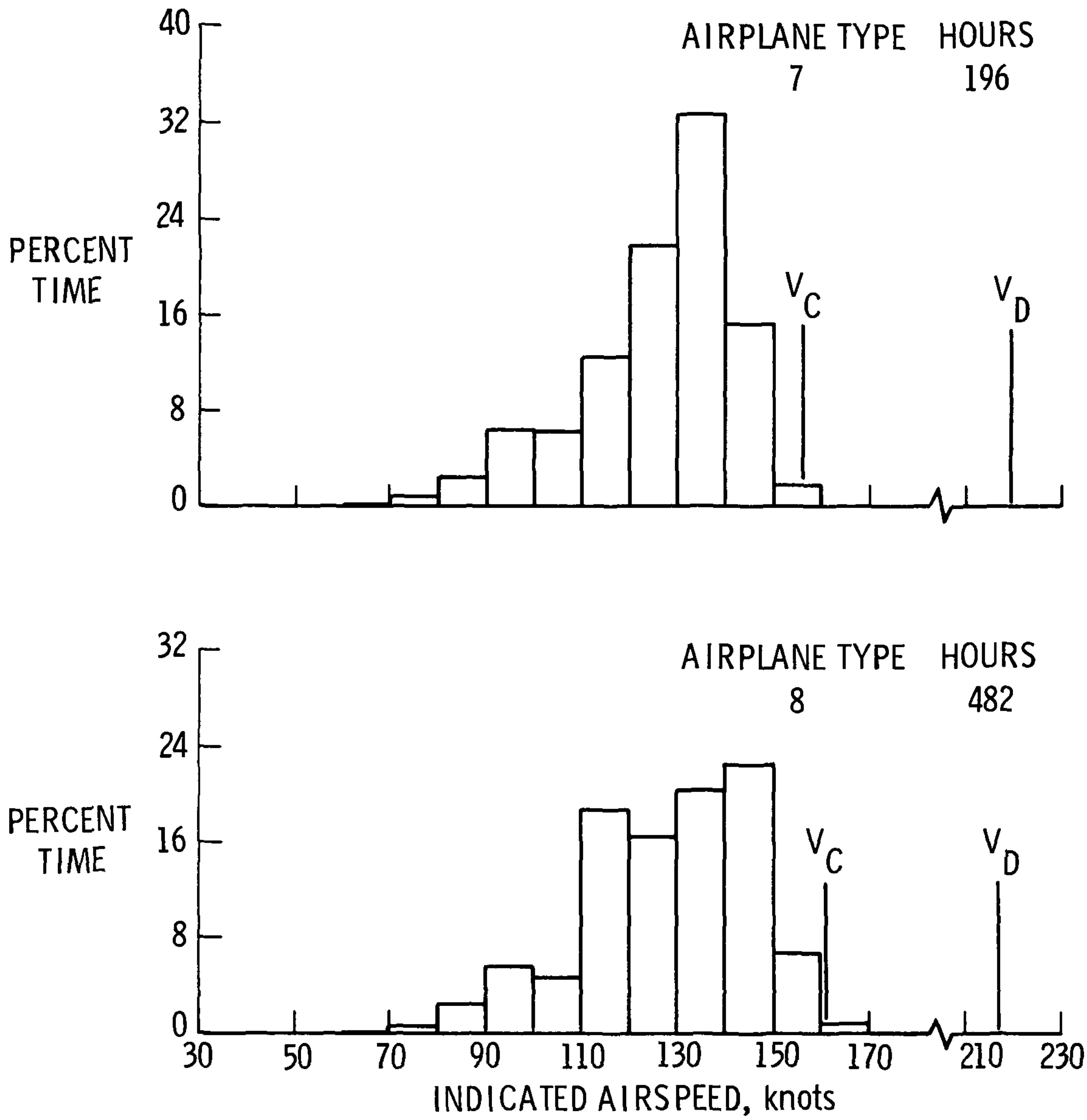
Figure 6.- Percent time flown in various airspeed intervals.





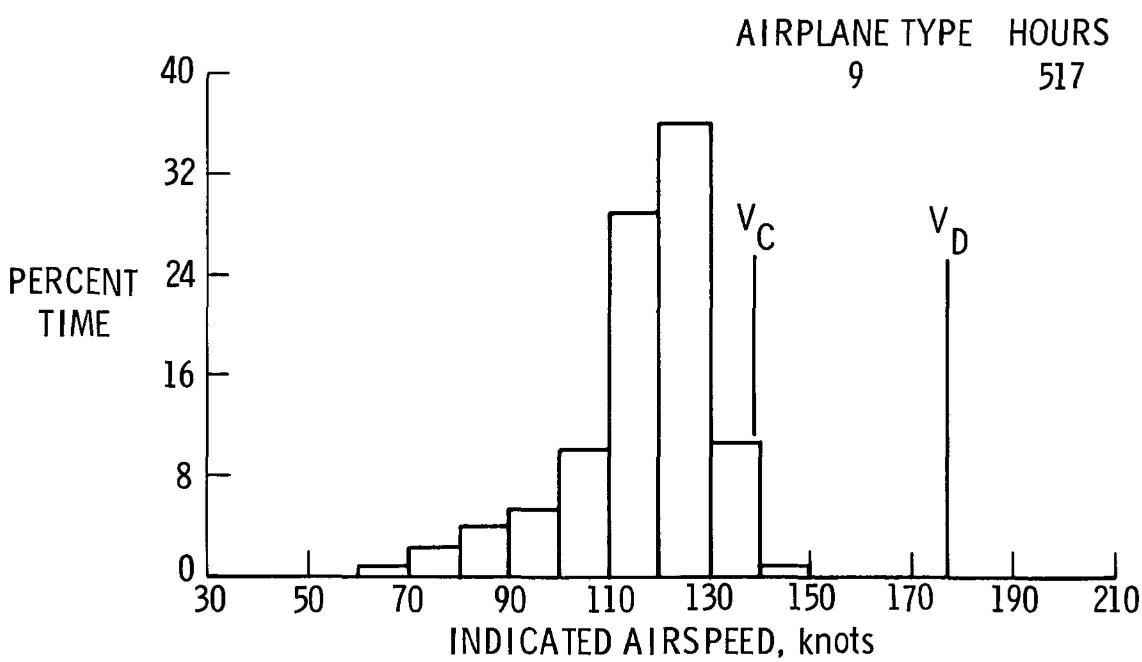
(a) Twin-engine executive. Concluded.

Figure 6.- Continued.



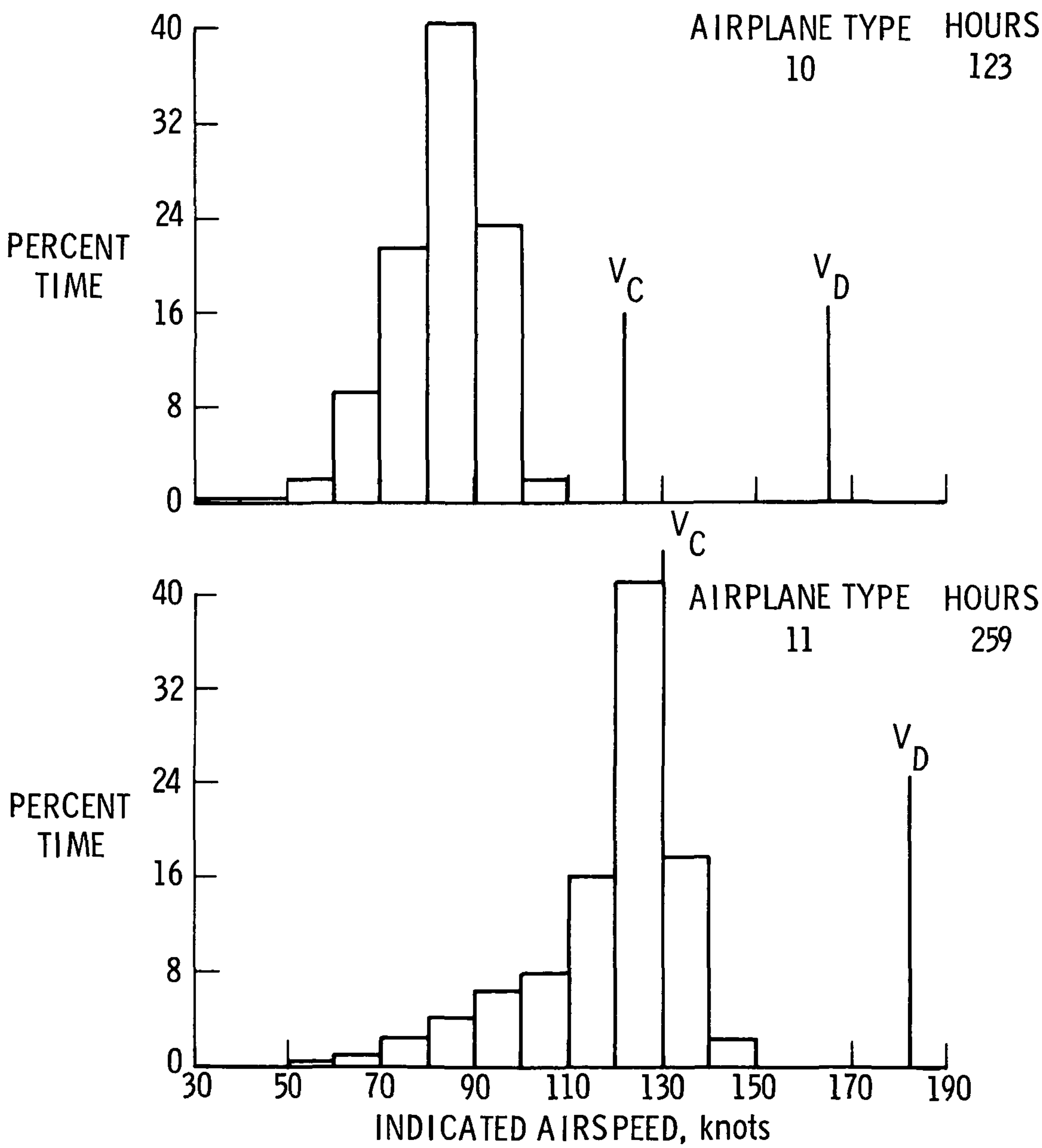
(b) Single-engine executive.

Figure 6.- Continued.



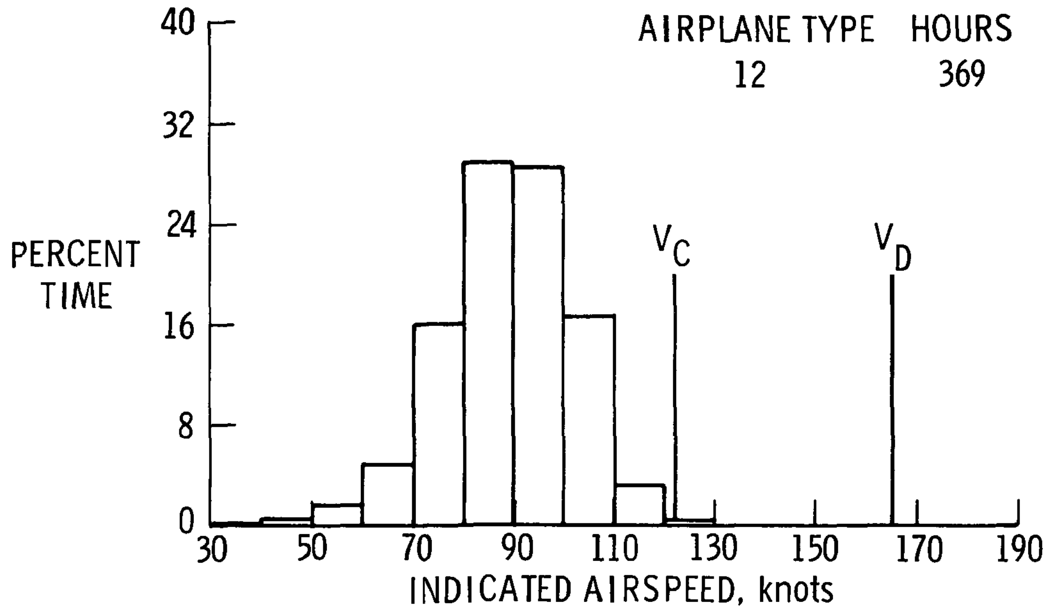
(b) Single-engine executive. Concluded.

Figure 6.- Continued.



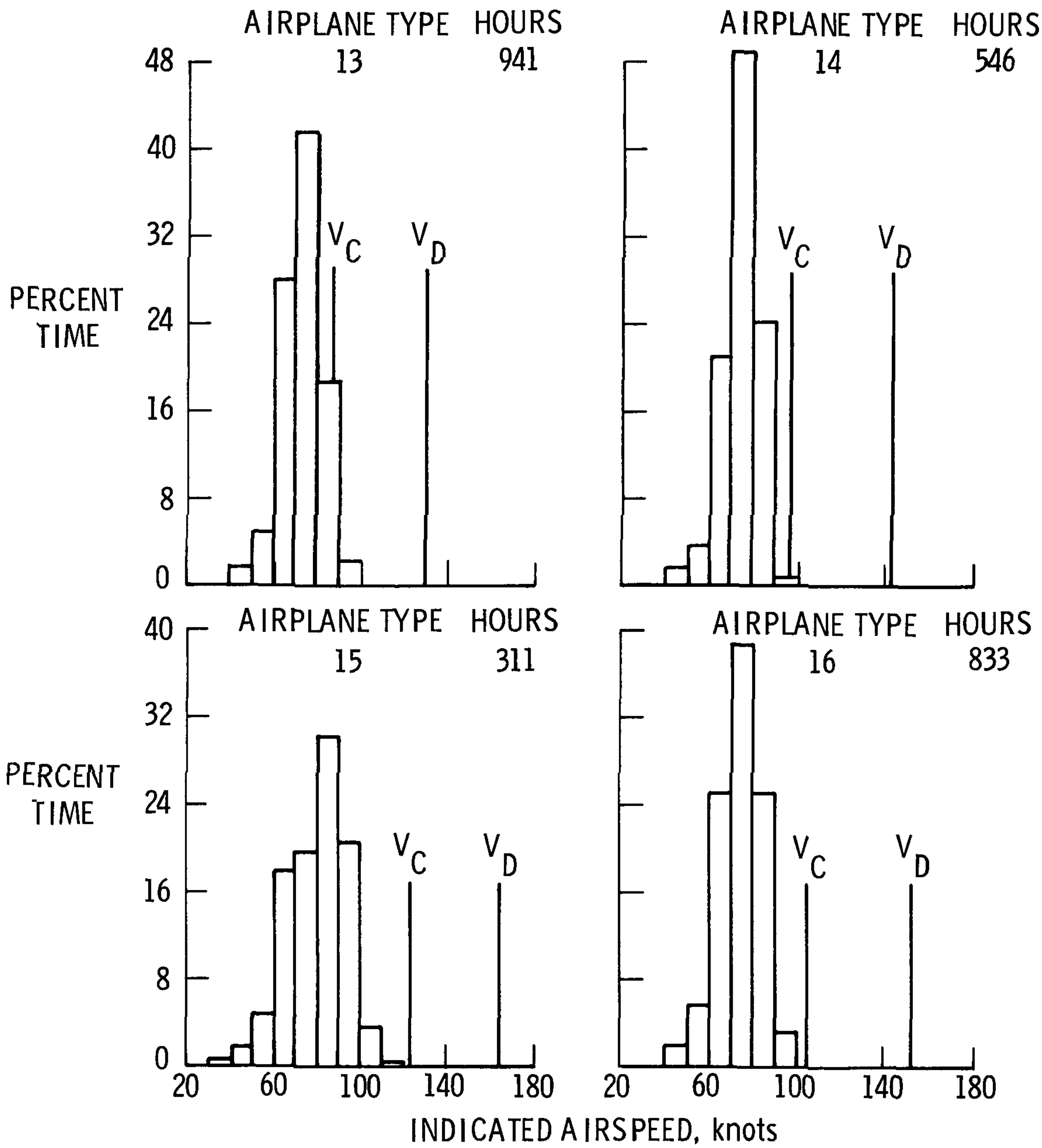
(c) Personal.

Figure 6.- Continued.



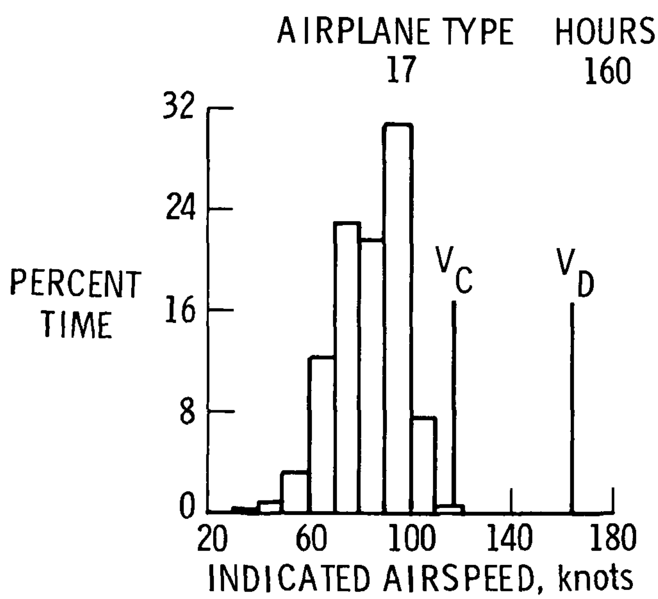
(c) Personal. Concluded.

Figure 6.- Continued.



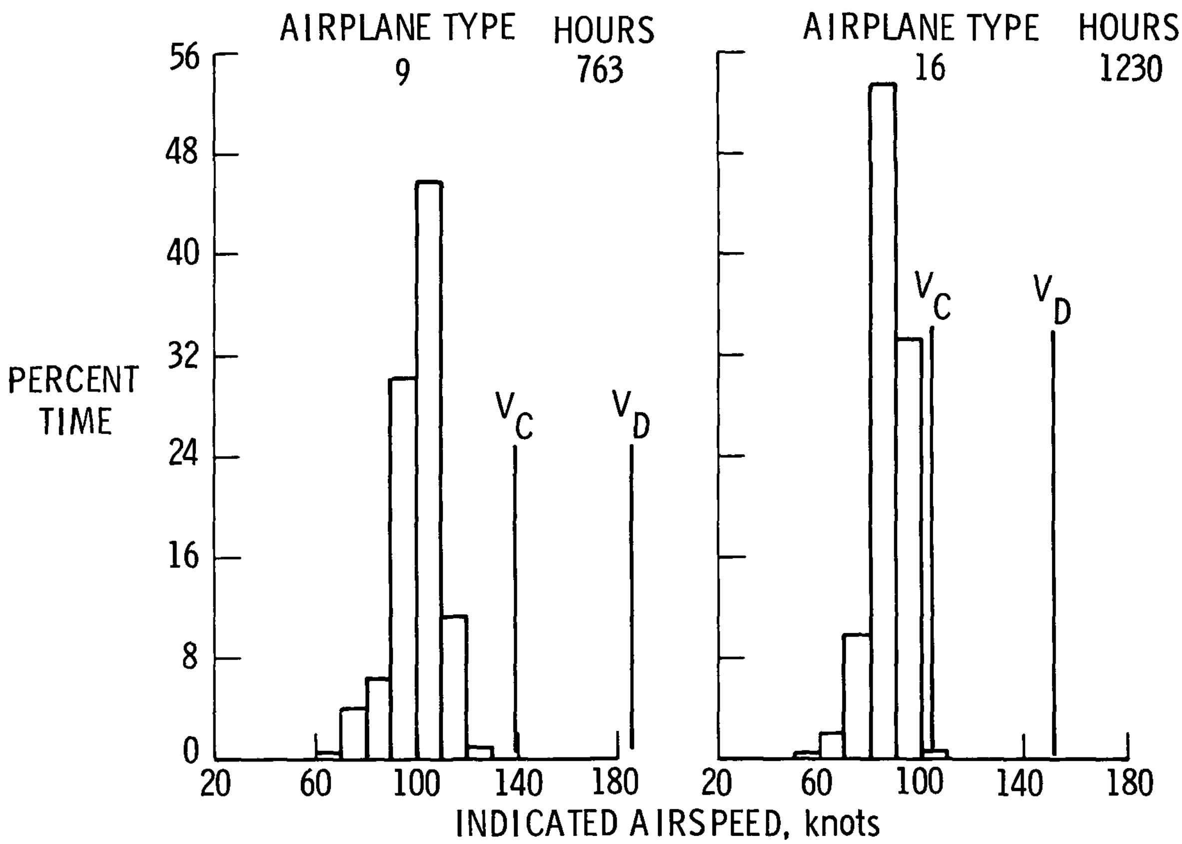
(d) Instructional.

Figure 6.- Continued.



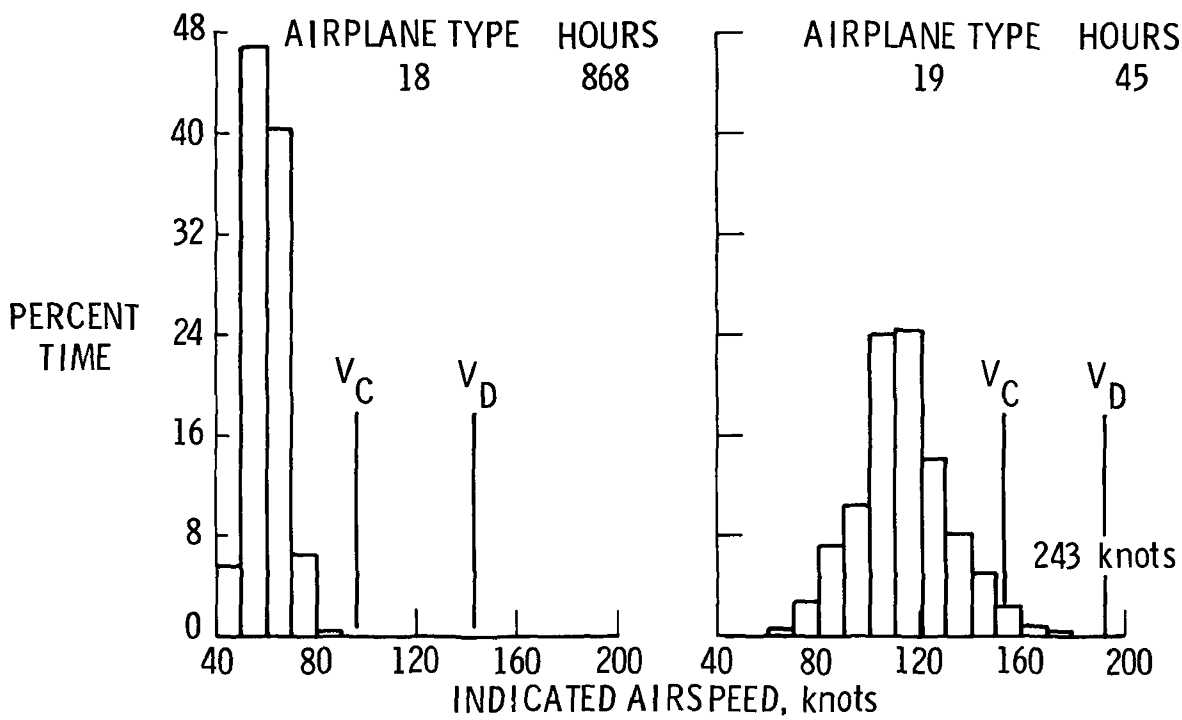
(d) Instructional. Concluded.

Figure 6. - Continued.



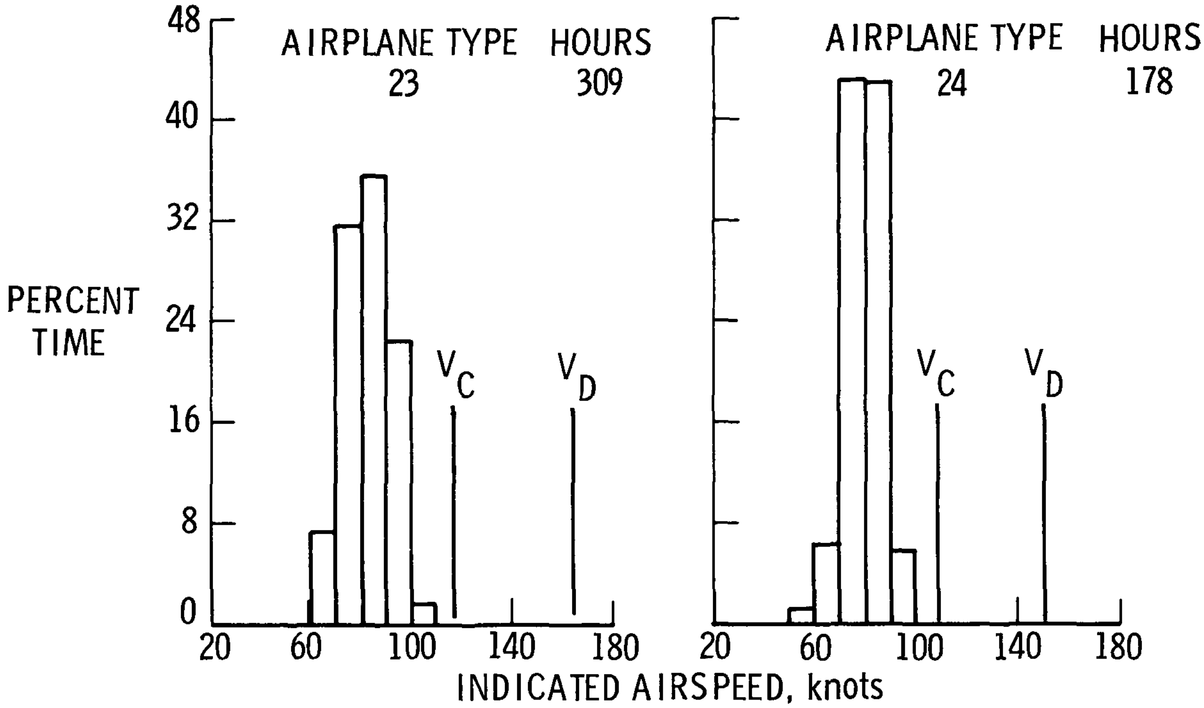
(e) Commercial survey.

Figure 6. - Continued.



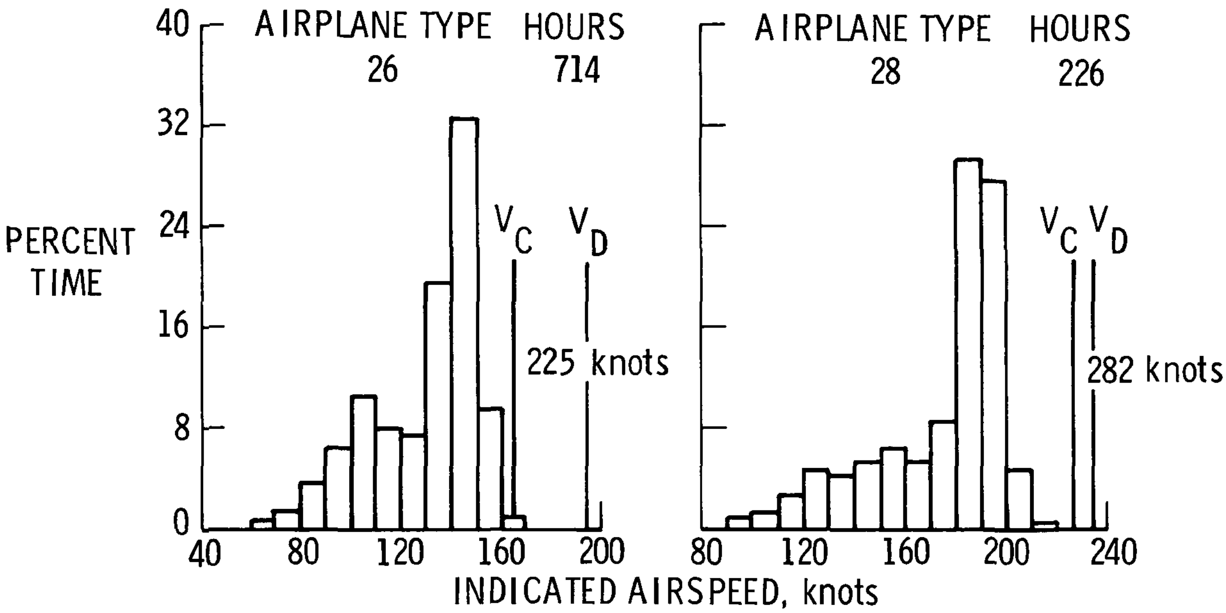
(e) Commercial survey. Concluded.

Figure 6.- Continued.



(f) Aerial application.

Figure 6. - Continued.



(g) Commuter.

Figure 6.- Concluded.

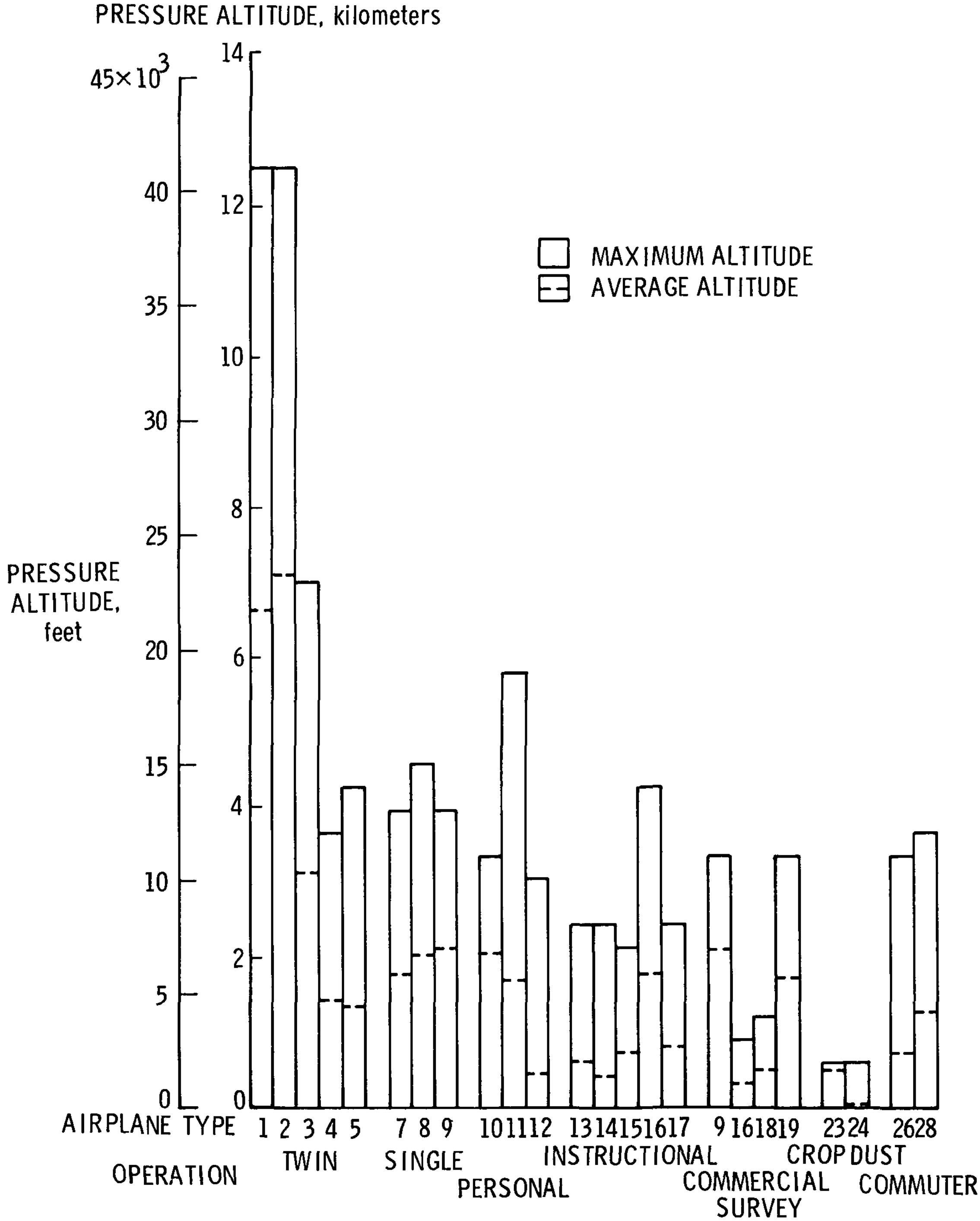
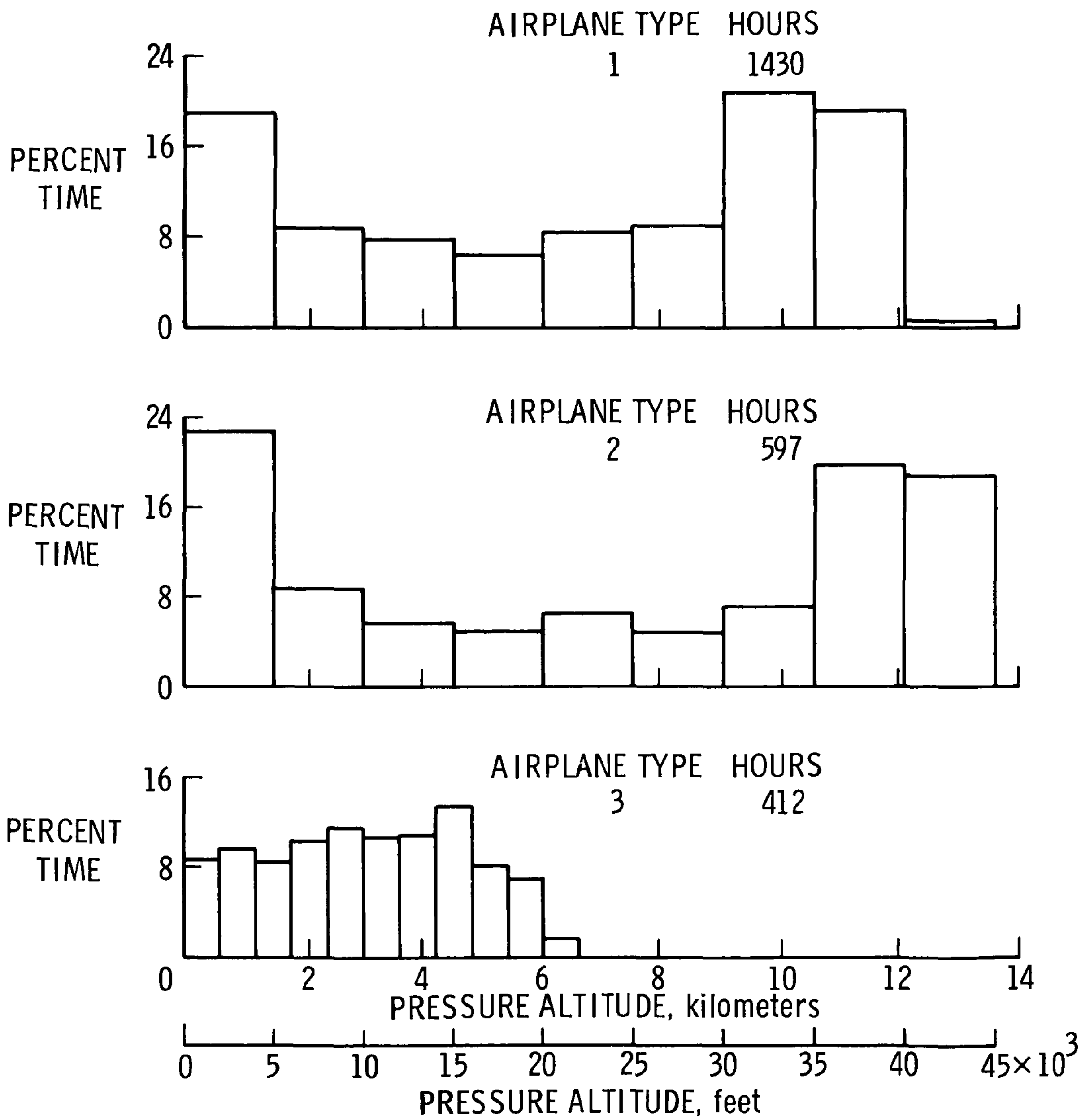
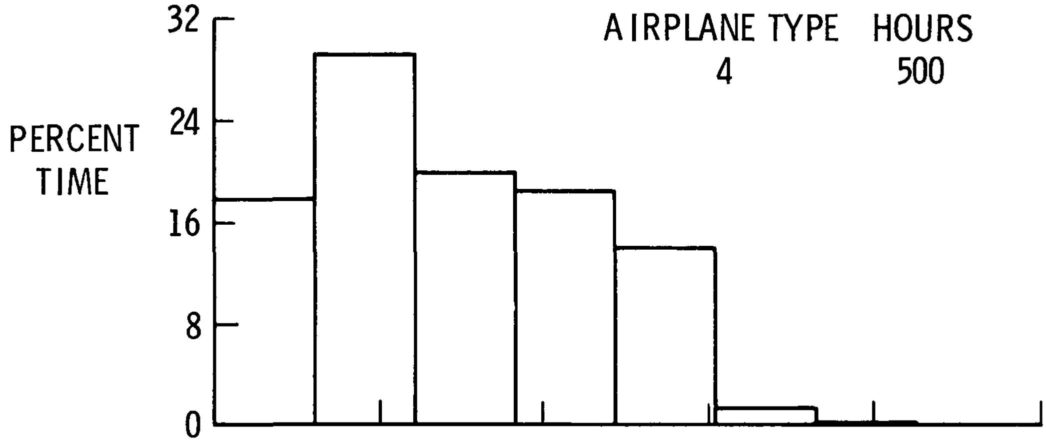


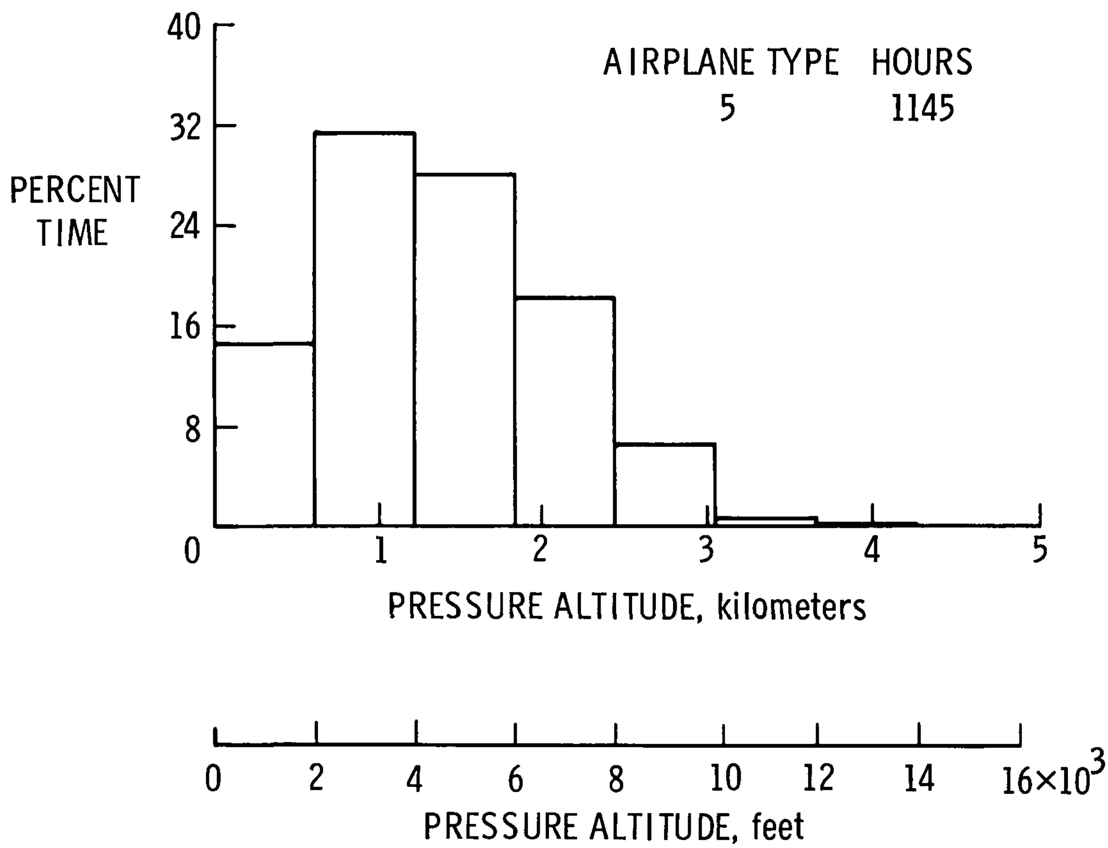
Figure 7. - Histogram of average and maximum altitudes recorded by general aviation airplanes.



(a) Twin-engine executive.

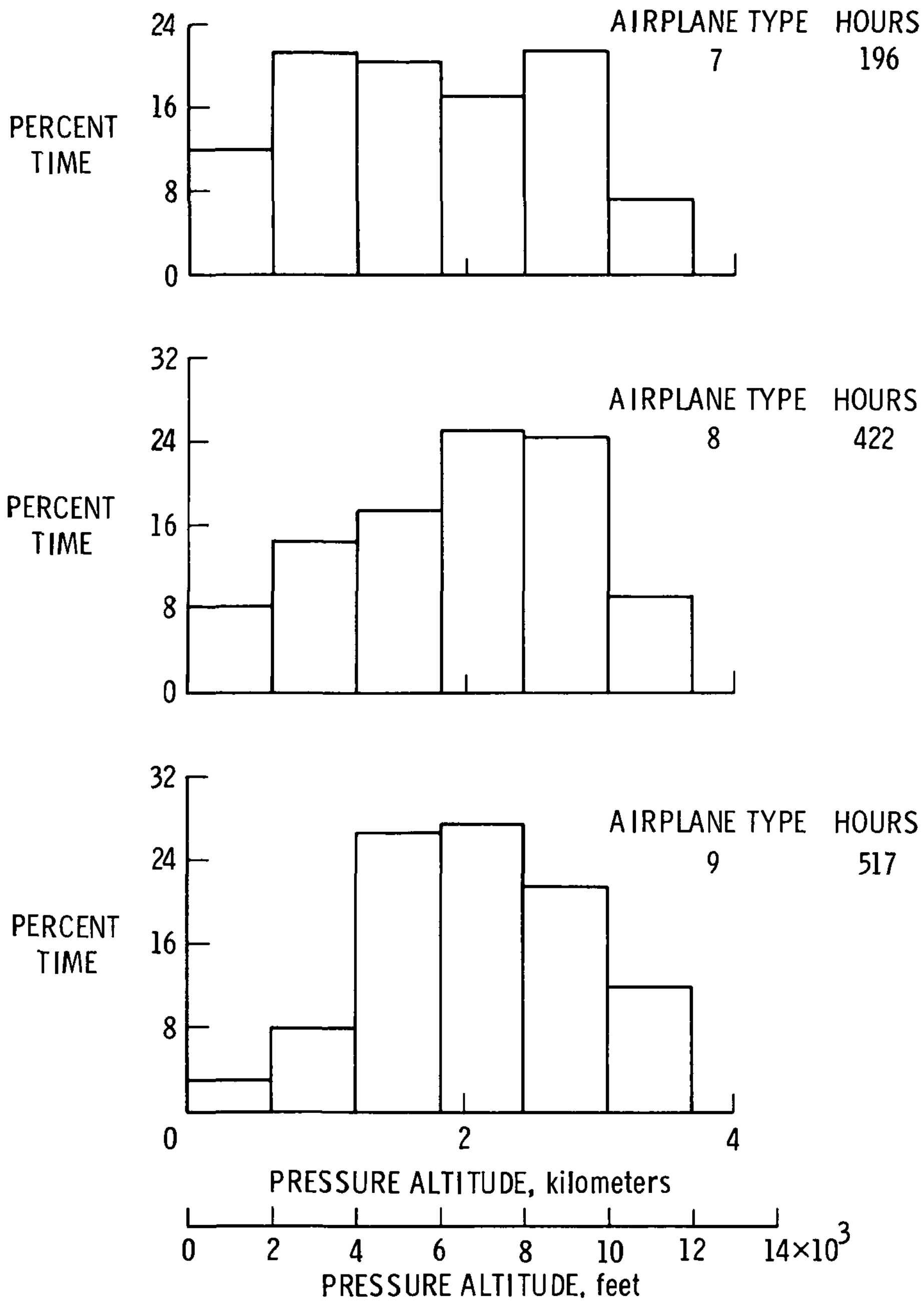
Figure 8.- Percent of time flown in various altitude intervals.





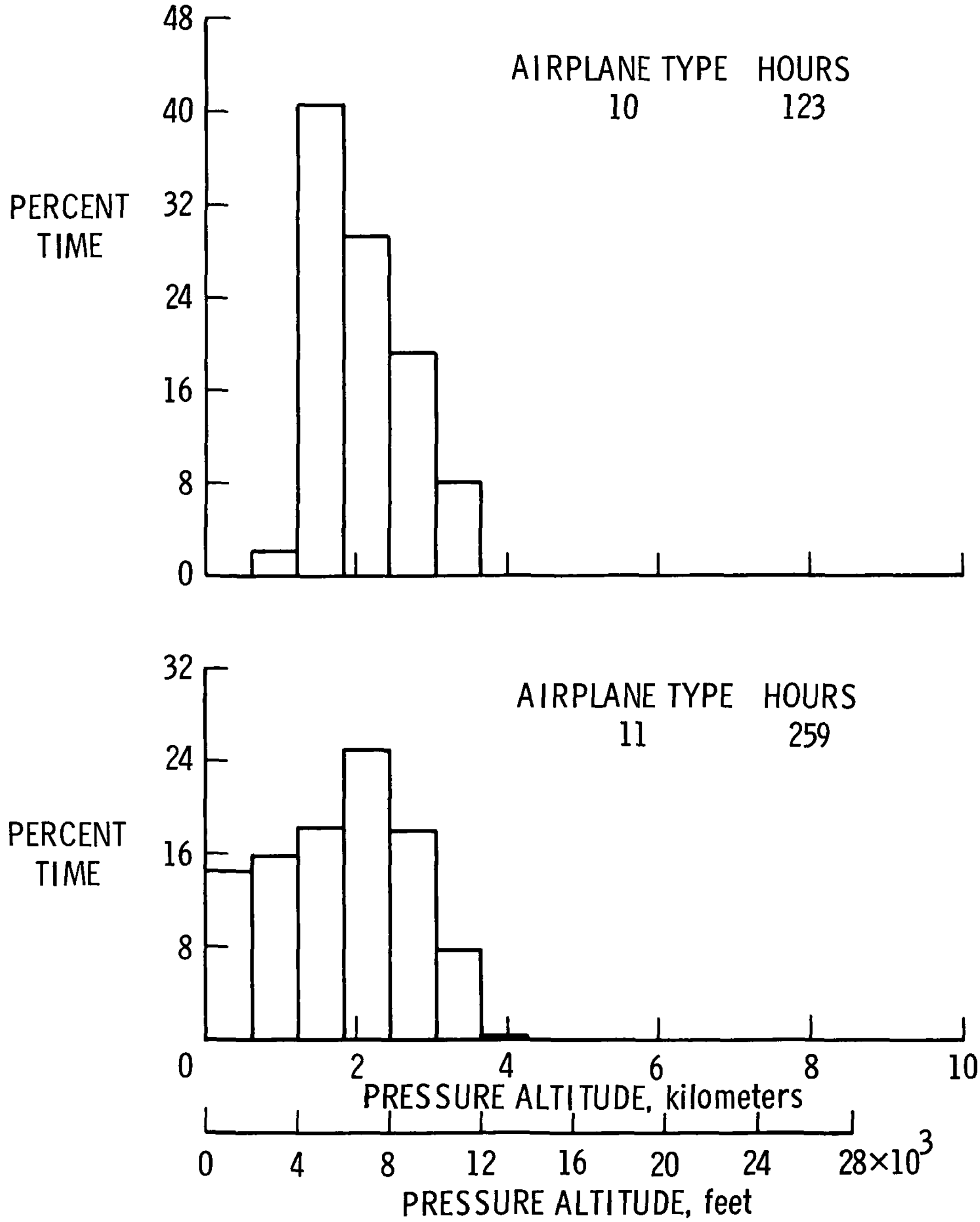
(a) Twin-engine executive. Concluded.

Figure 8. - Continued.



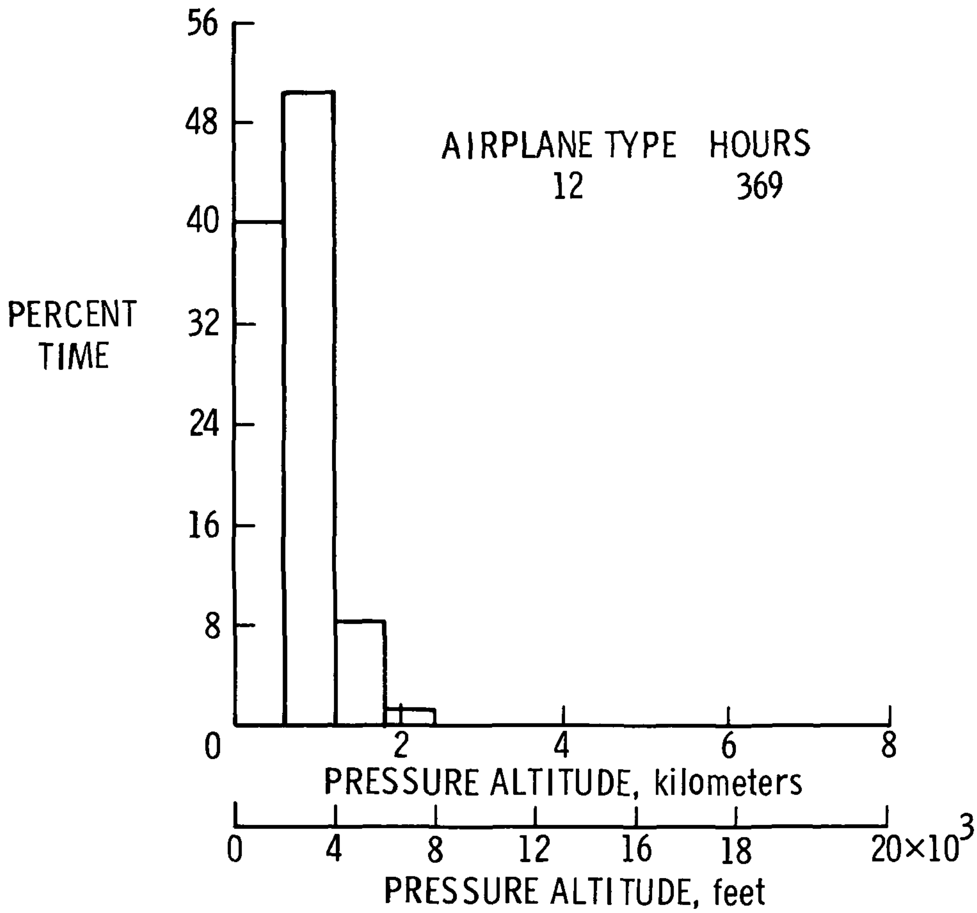
(b) Single-engine executive.

Figure 8. - Continued.



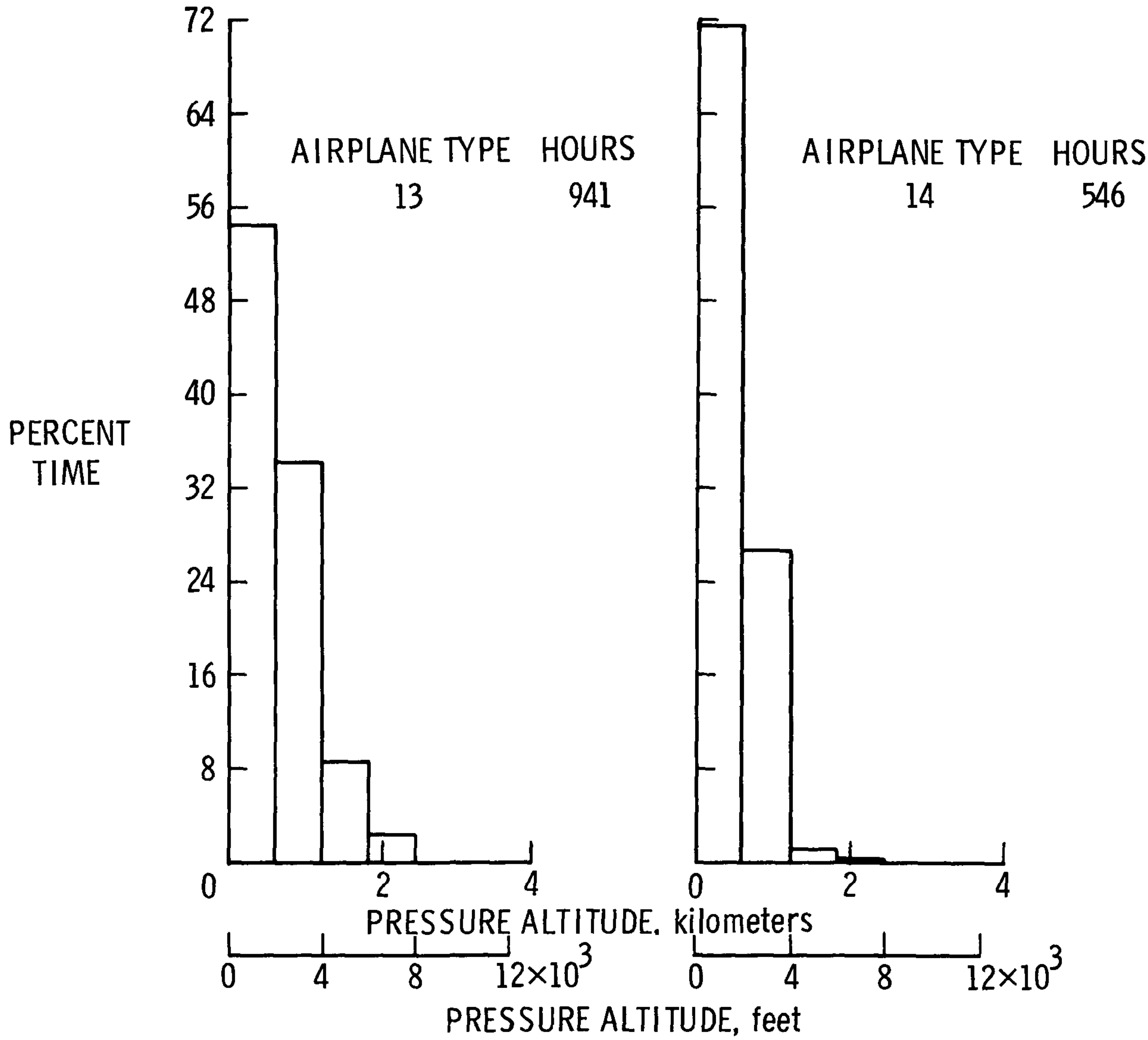
(c) Personal.

Figure 8.- Continued.



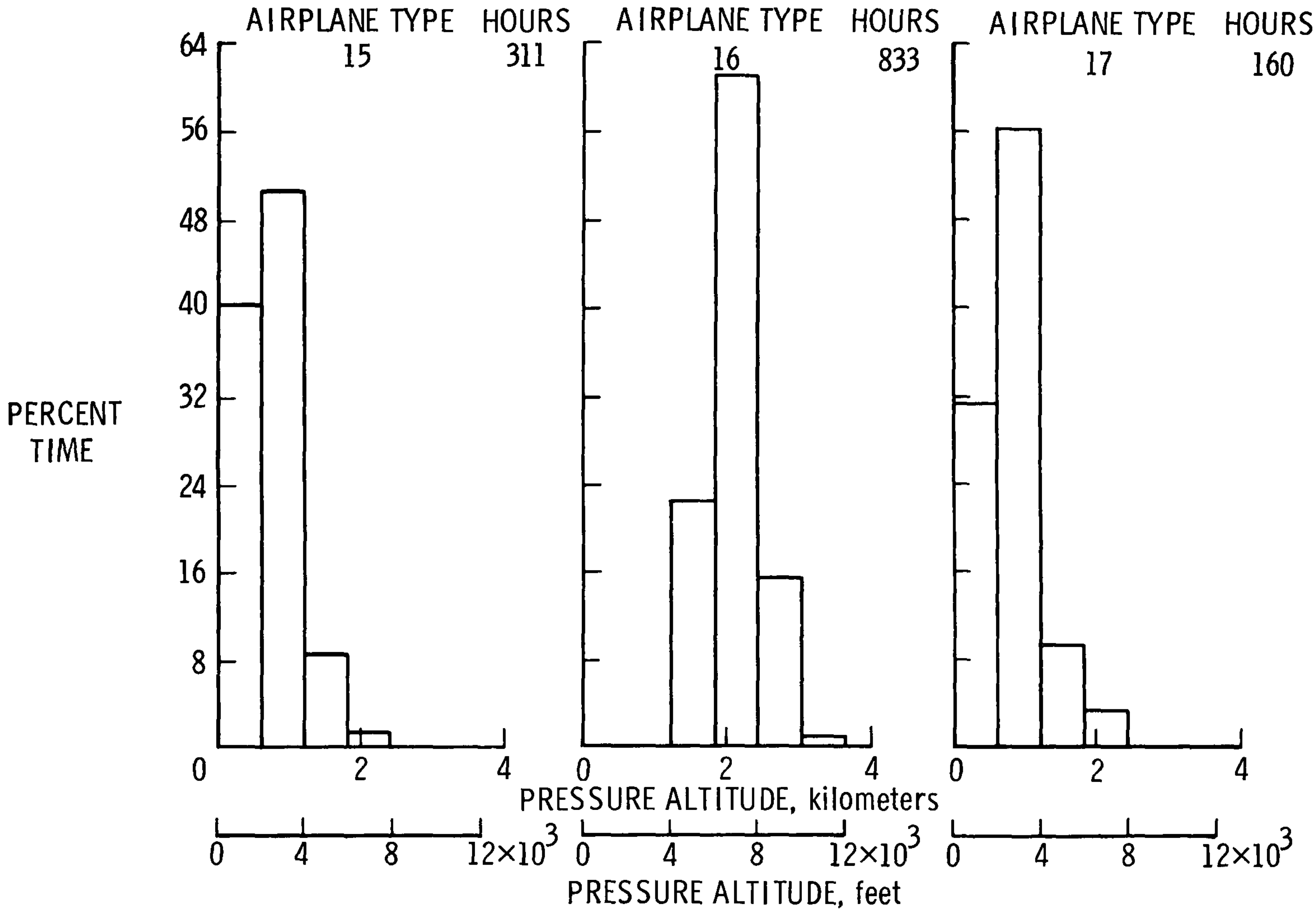
(c) Personal. Concluded.

Figure 8.- Continued.



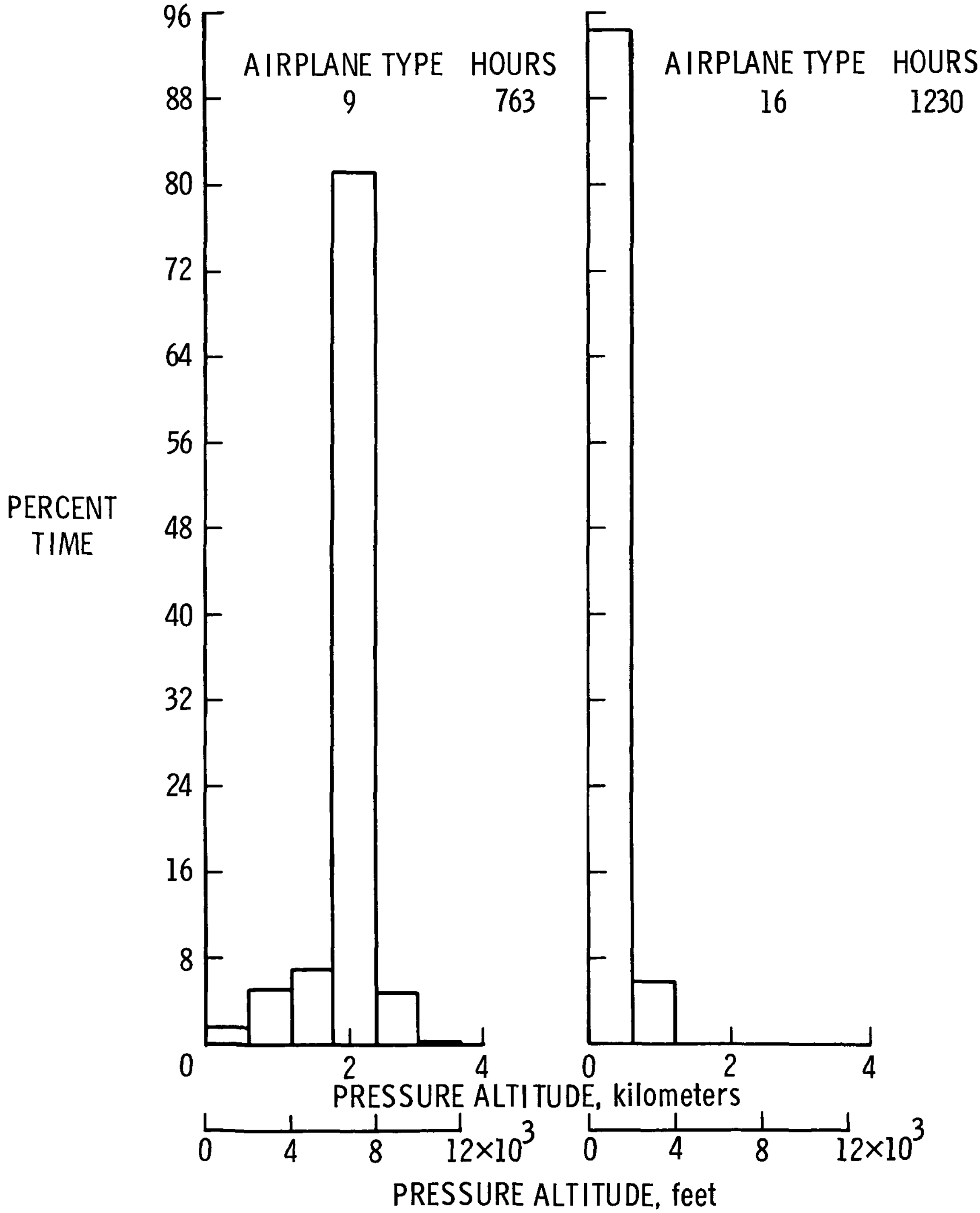
(d) Instructional.

Figure 8.- Continued.



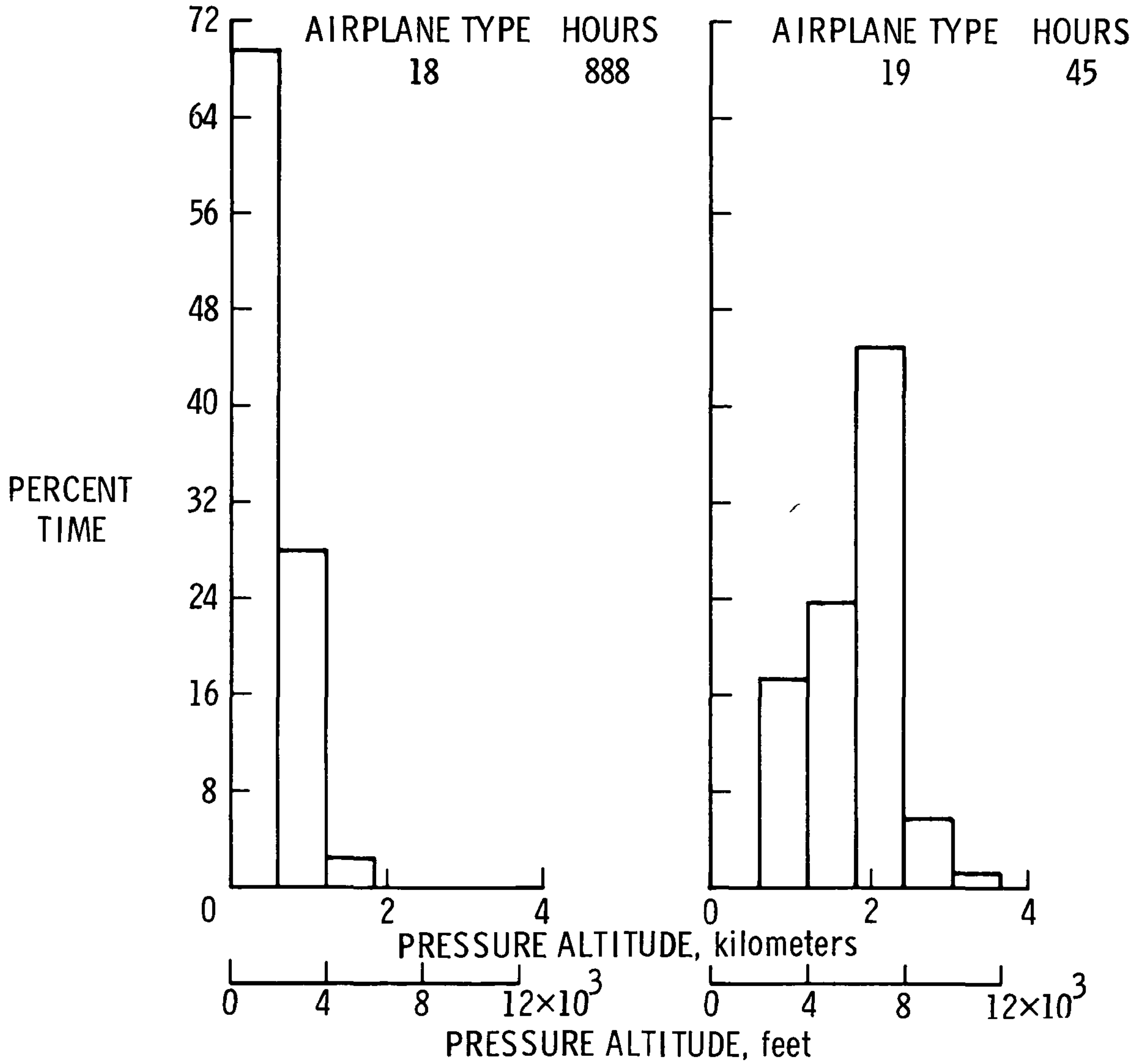
(d) Instructional. Concluded.

Figure 8.- Continued.



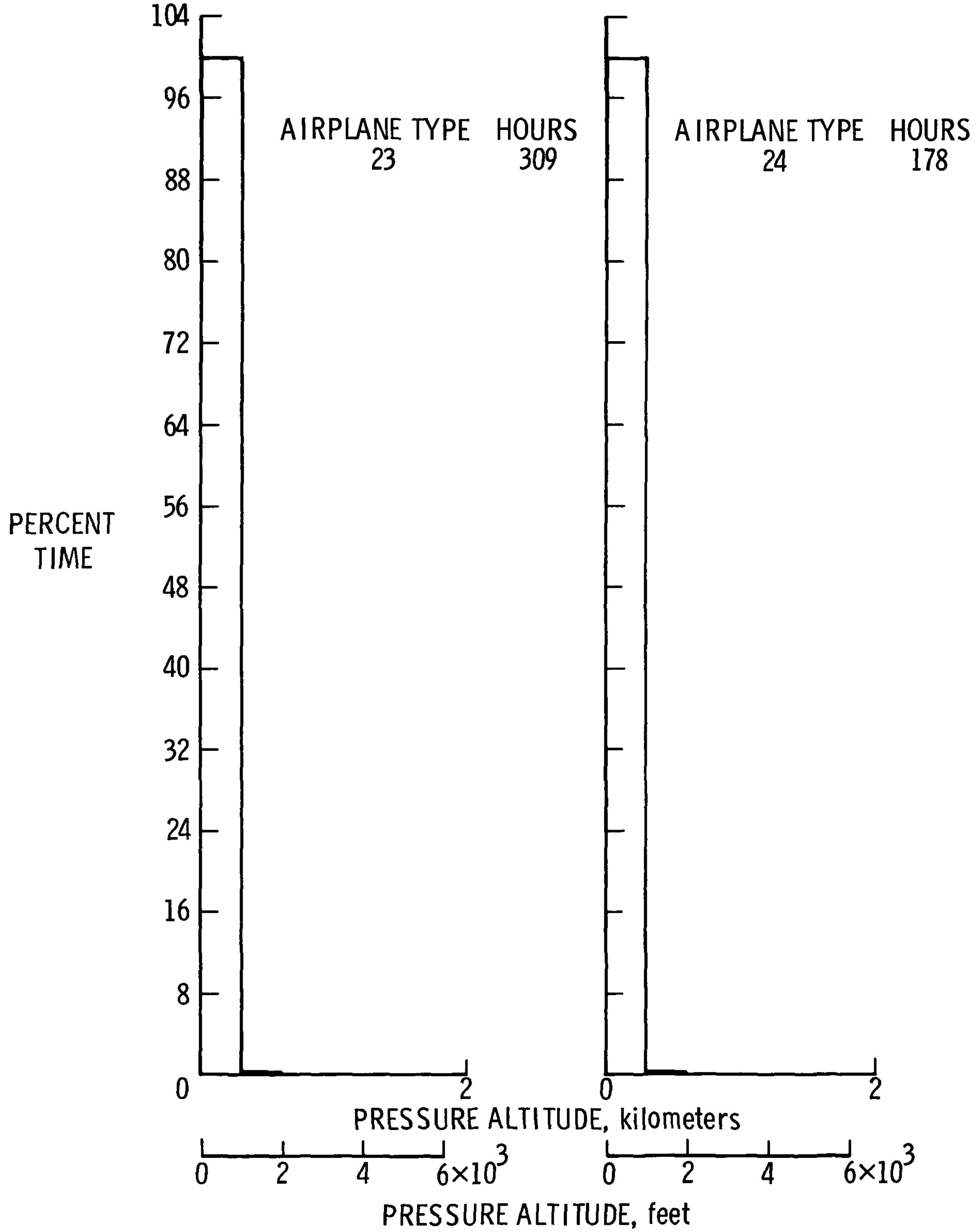
(e) Commercial survey.

Figure 8.- Continued.



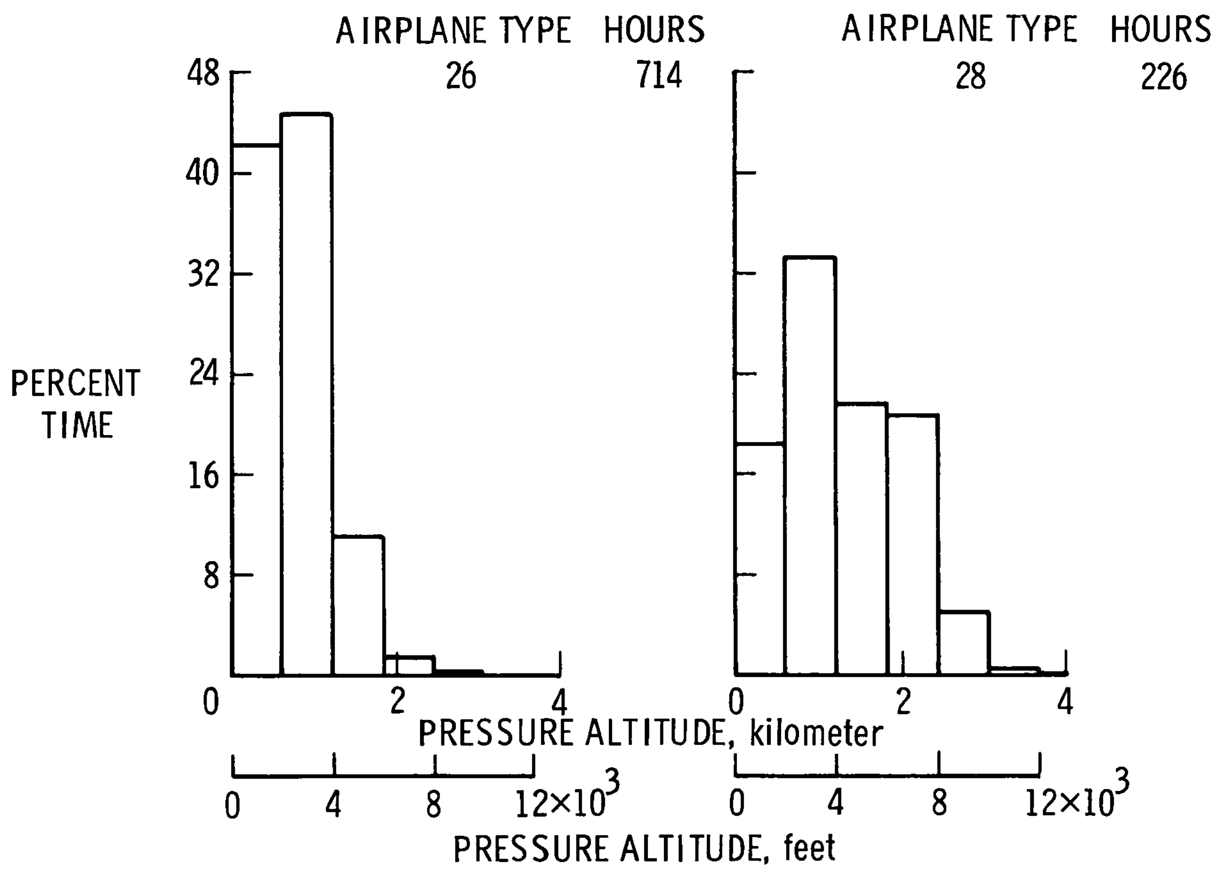
(e) Commercial survey. Concluded.

Figure 8.- Continued.



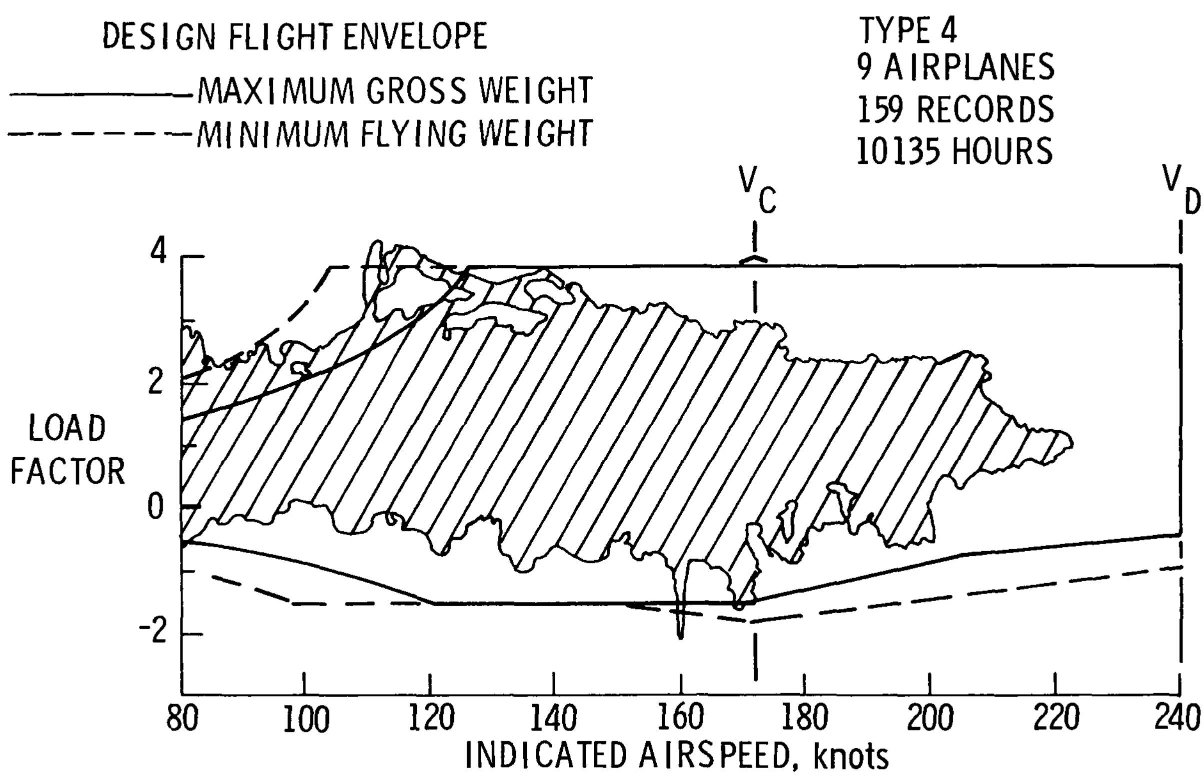
(f) Aerial application.

Figure 8.- Continued.



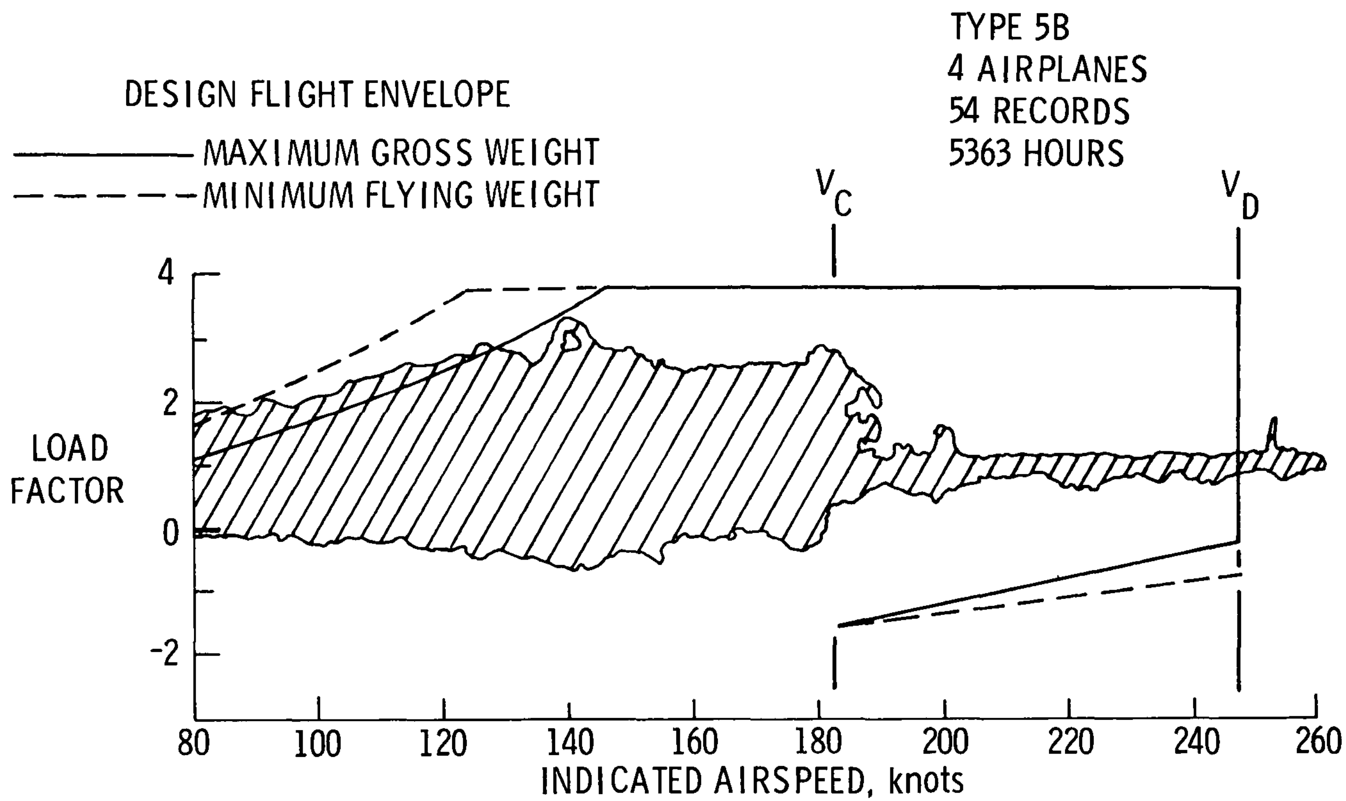
(g) Commuter.

Figure 8.- Concluded.



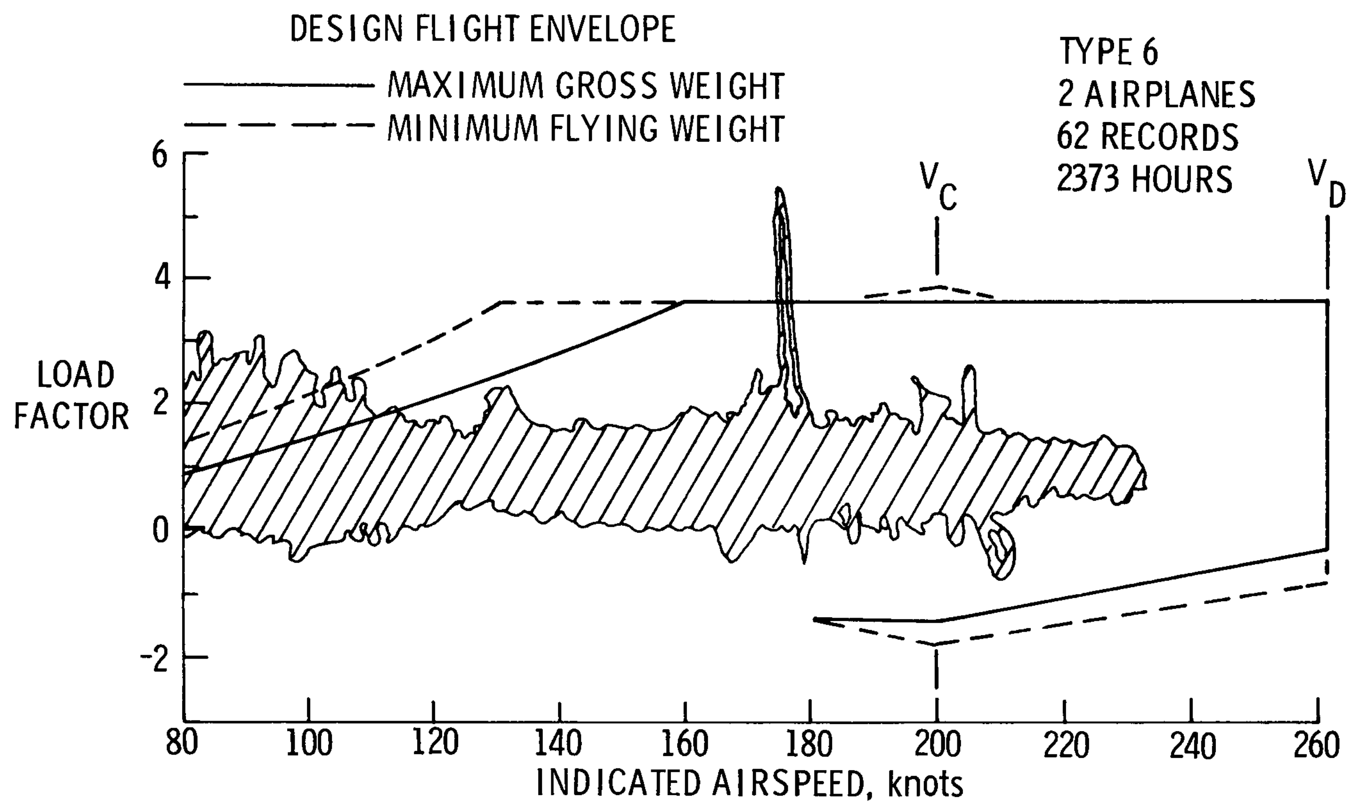
(a) Twin-engine executive.

Figure 9.- Design flight envelope exceedances recorded by airplanes in various types of operations.



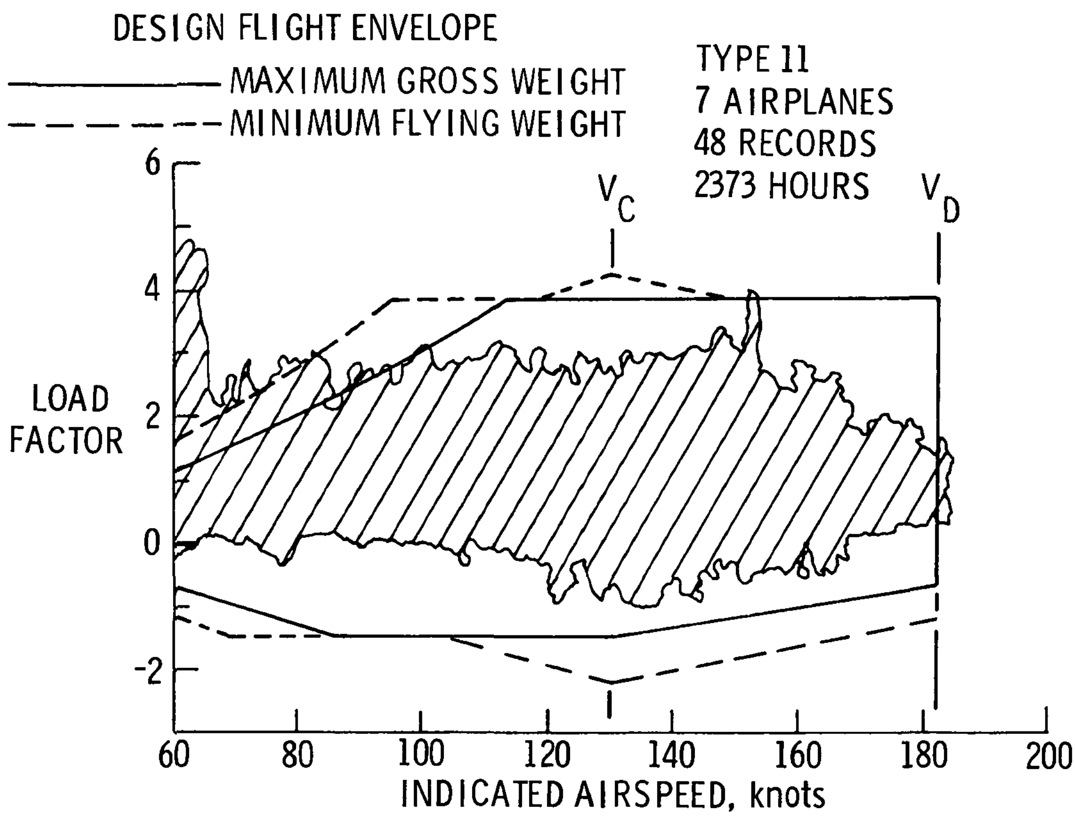
(a) Twin-engine executive. Continued.

Figure 9.- Continued.



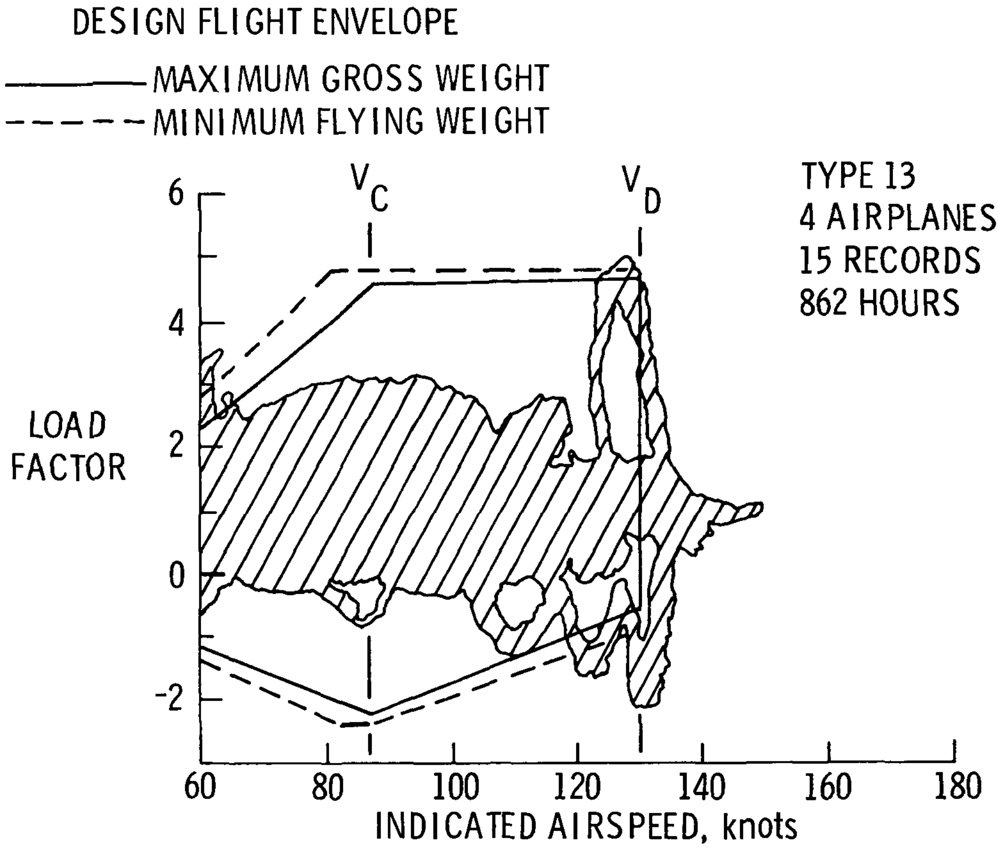
(a) Twin-engine executive. Concluded.

Figure 9.- Continued.



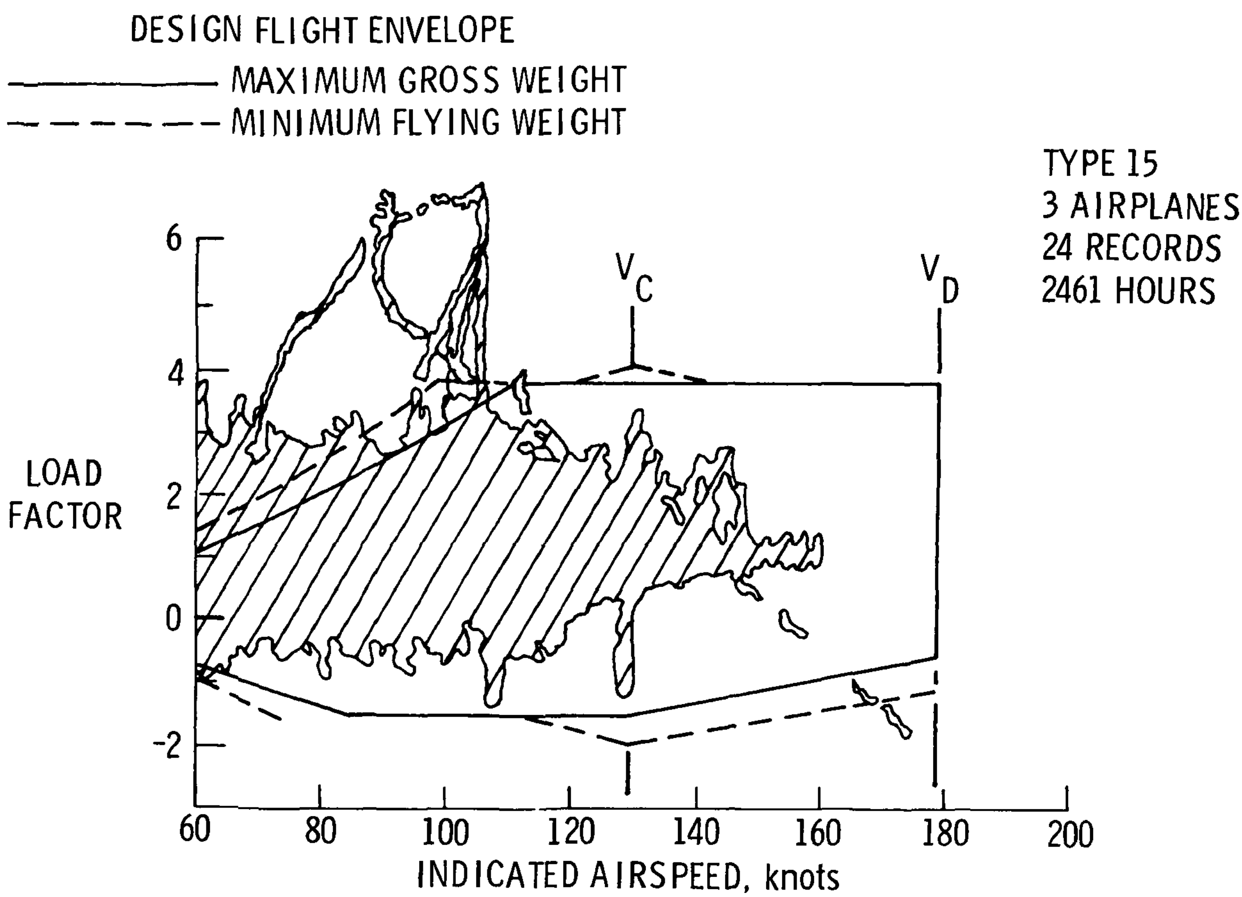
(b) Personal.

Figure 9.- Continued.



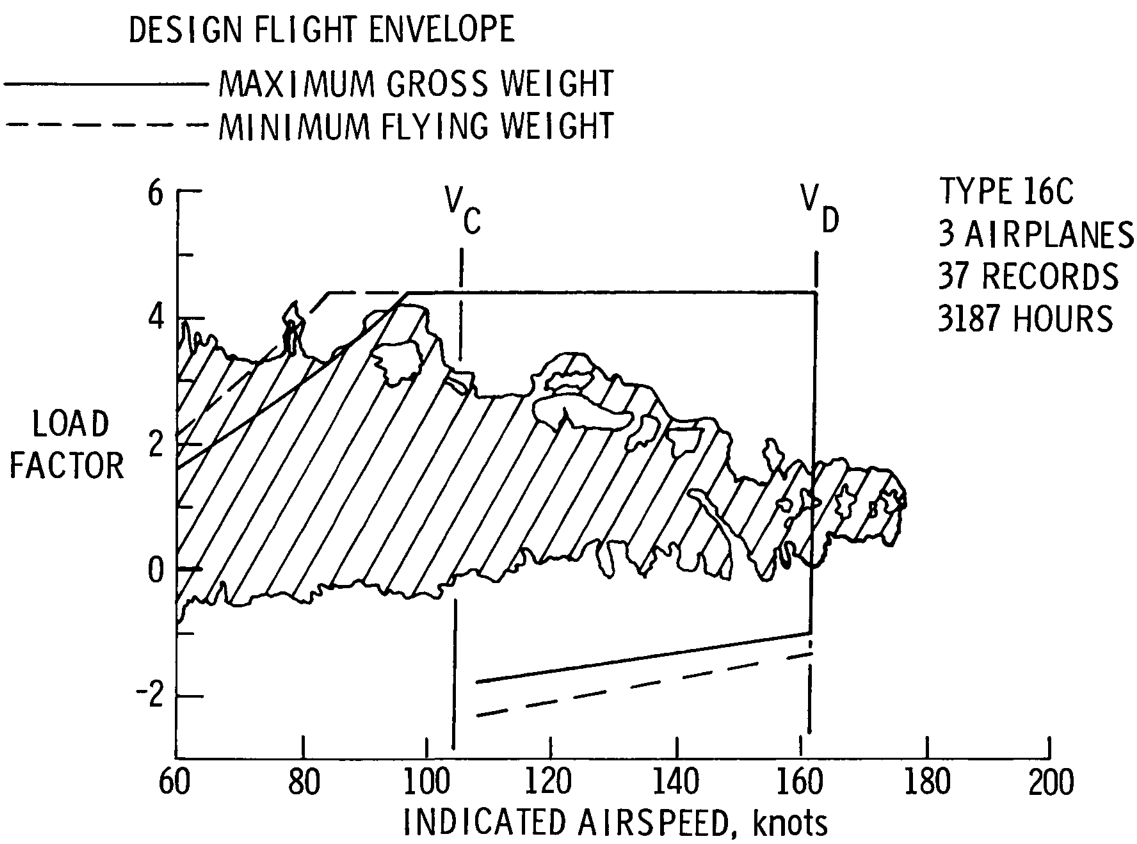
(c) Instructional.

Figure 9.- Continued.



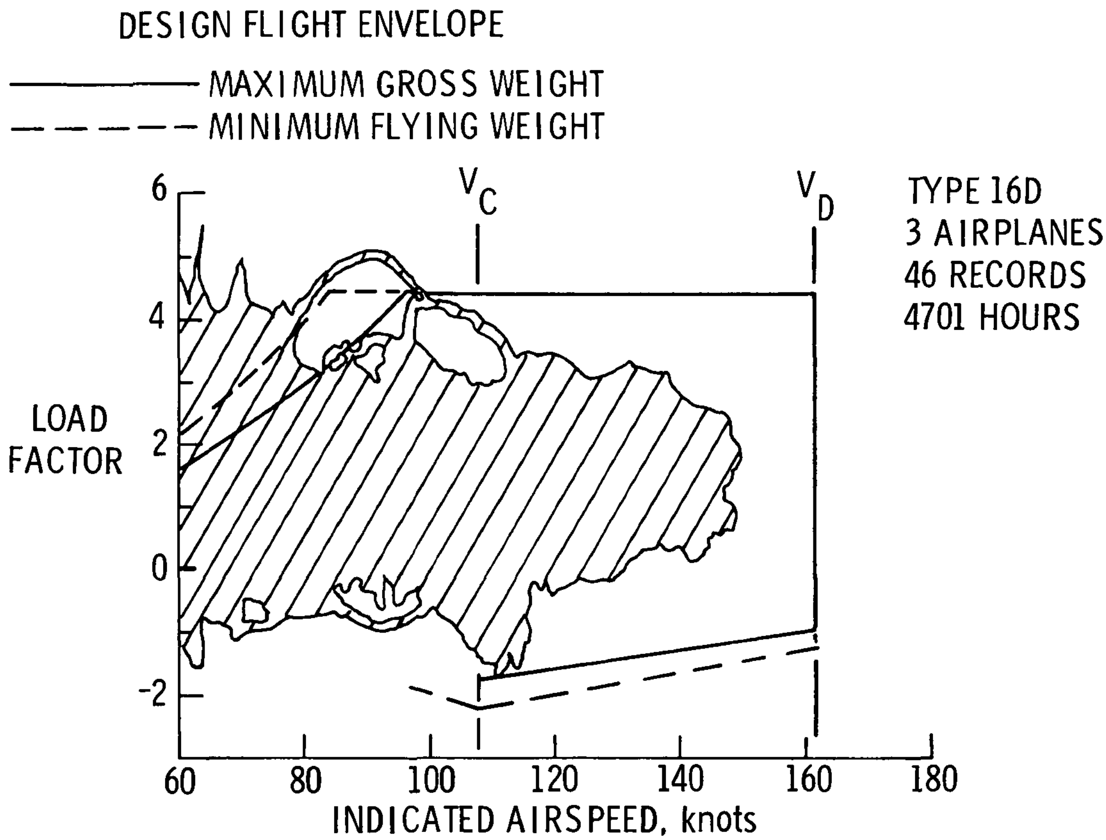
(c) Instructional. Continued.

Figure 9.- Continued.



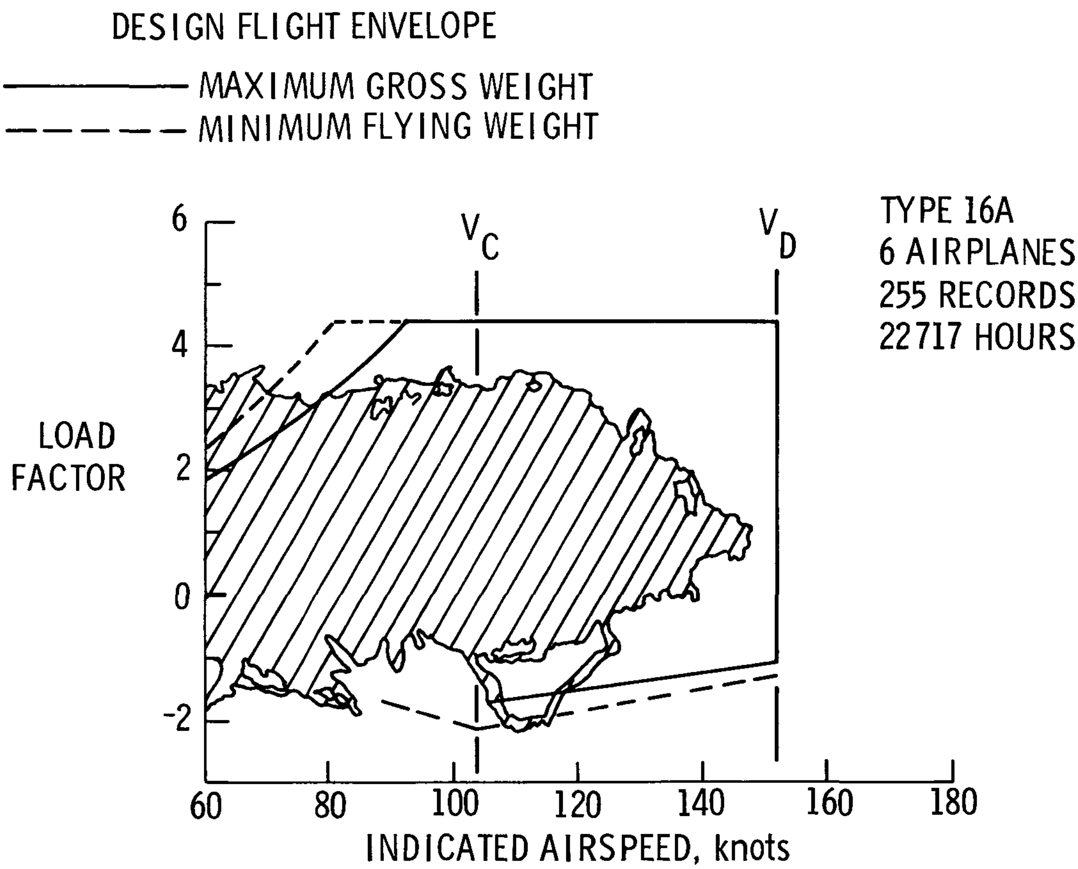
(c) Instructional. Continued.

Figure 9.- Continued.



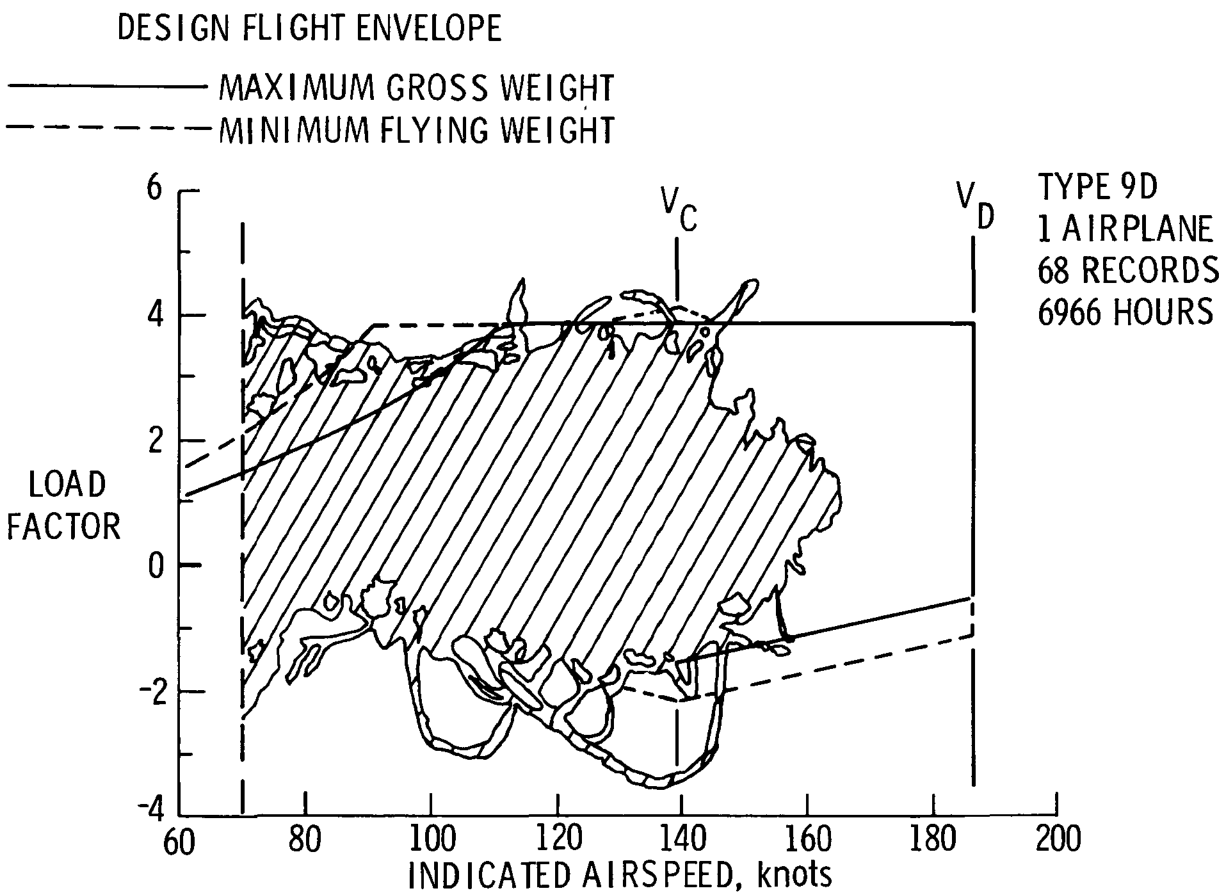
(c) Instructional. Concluded.

Figure 9.- Continued.



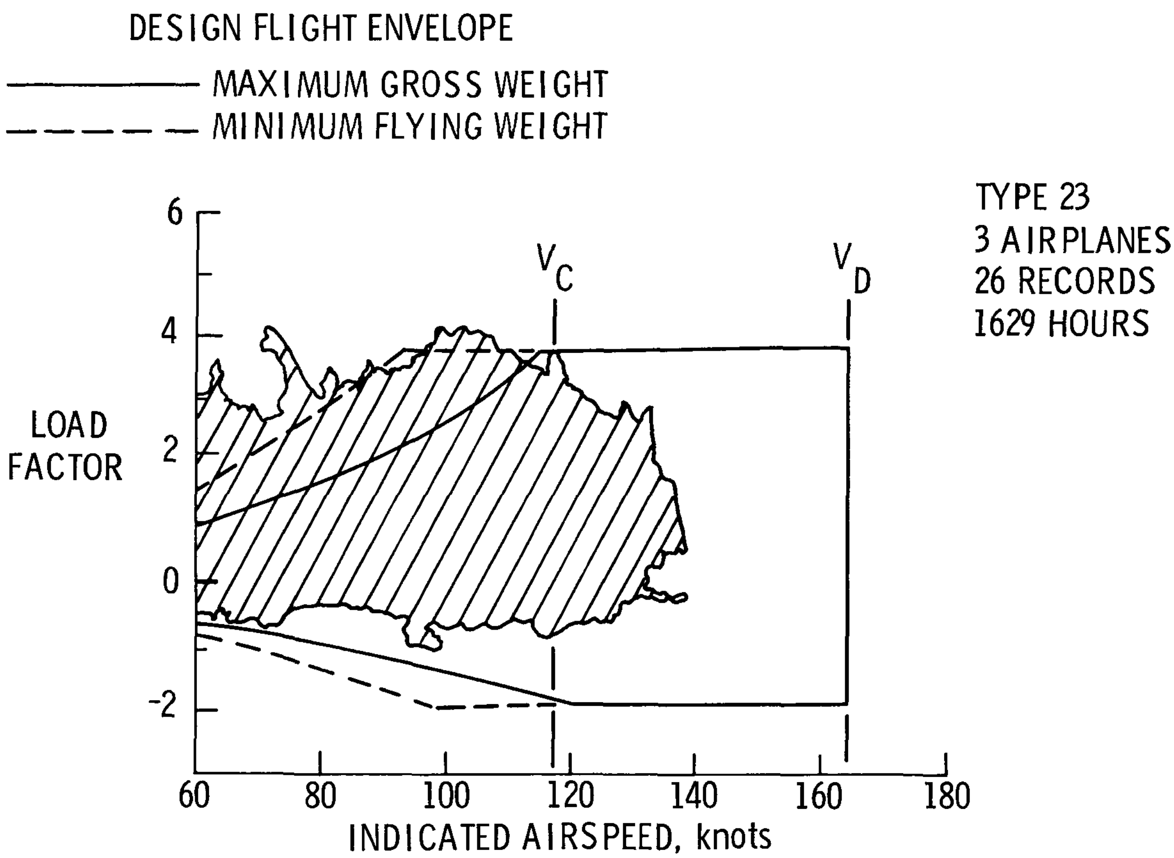
(d) Commercial survey.

Figure 9.- Continued.



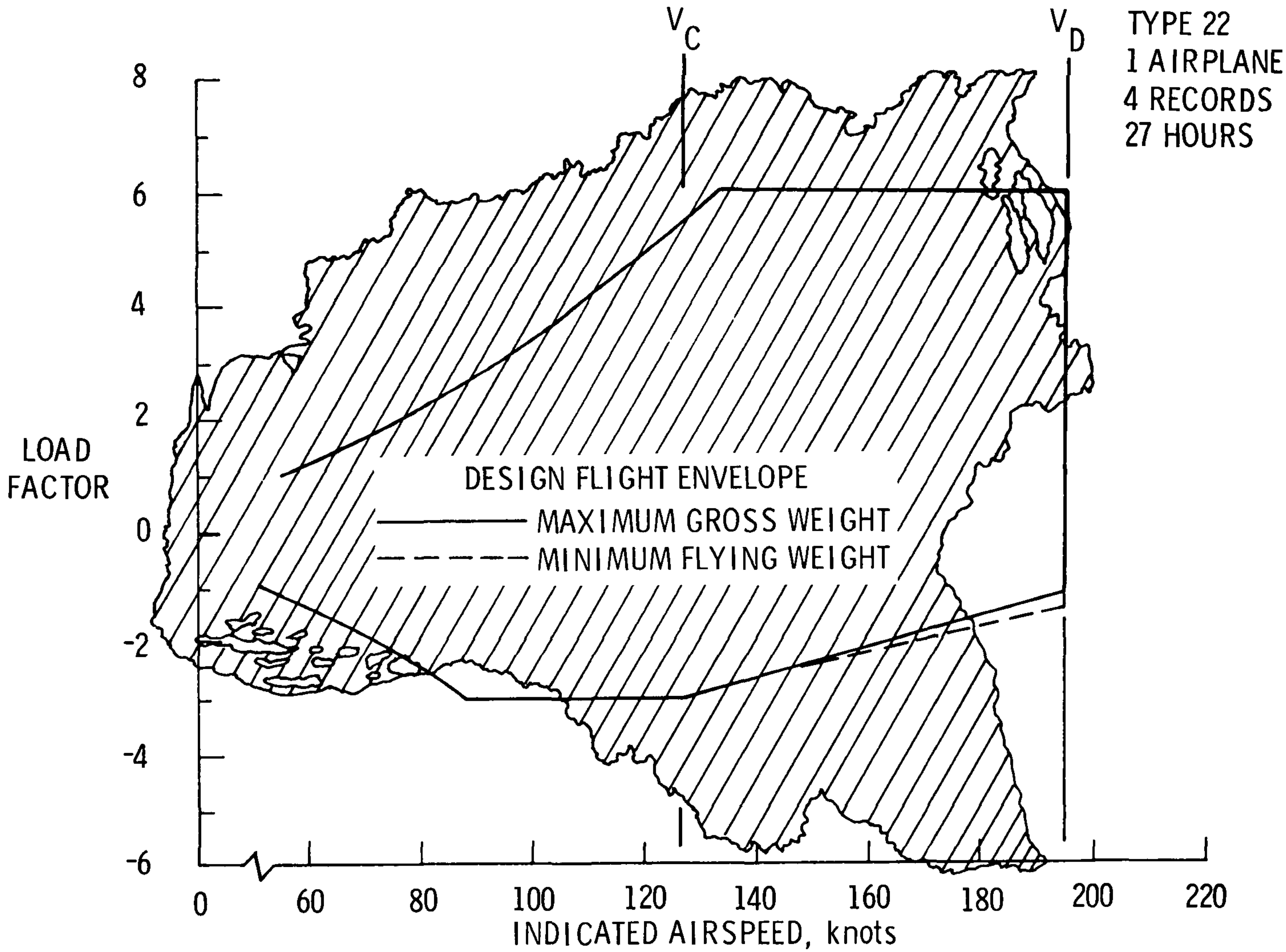
(d) Commercial survey. Concluded.

Figure 9.- Continued



(e) Aerial application.

Figure 9.- Continued.



(f) Aerobatic.

Figure 9.- Concluded.

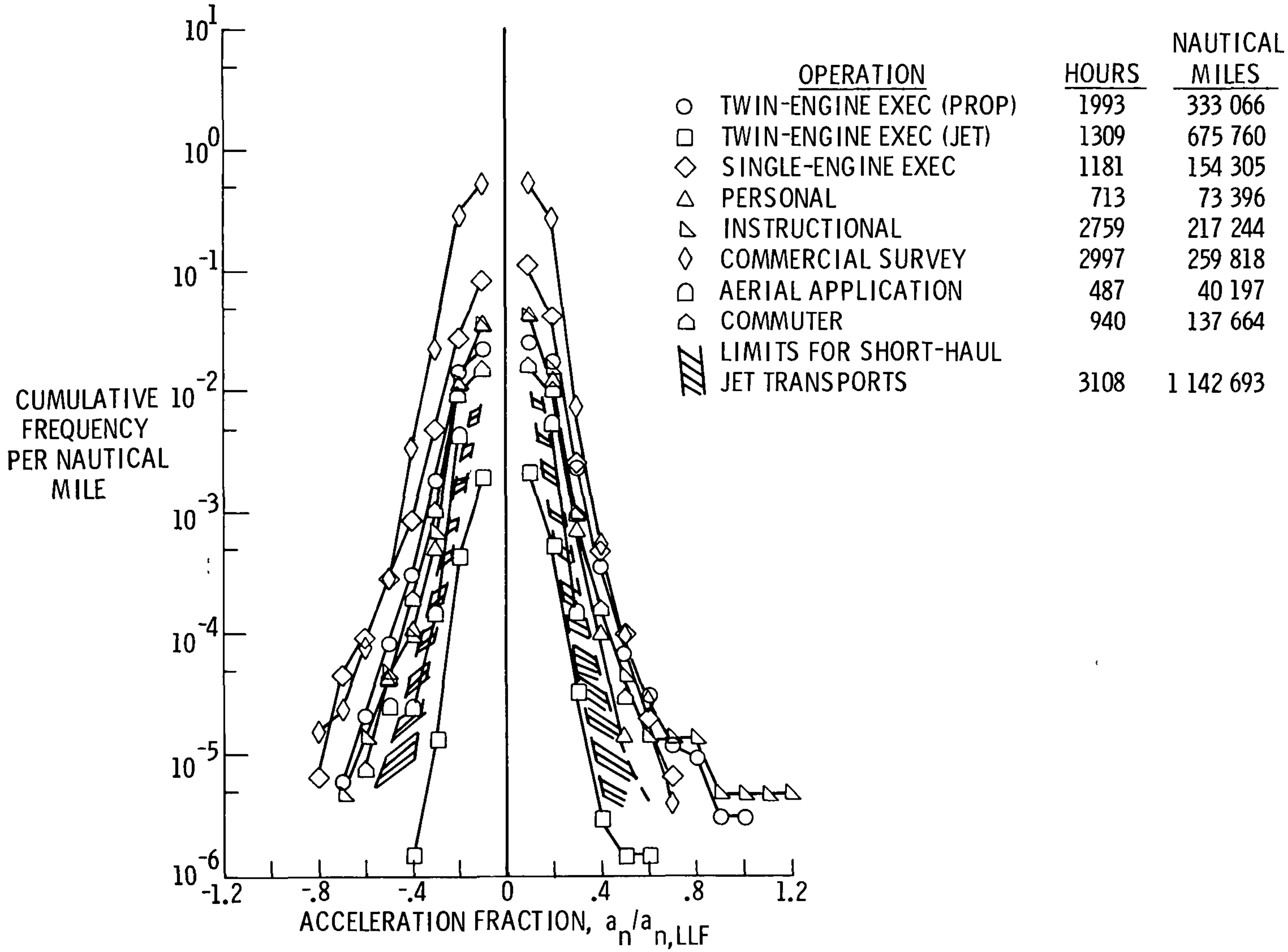


Figure 10.- Comparison of gust acceleration fractions experienced during various operations.

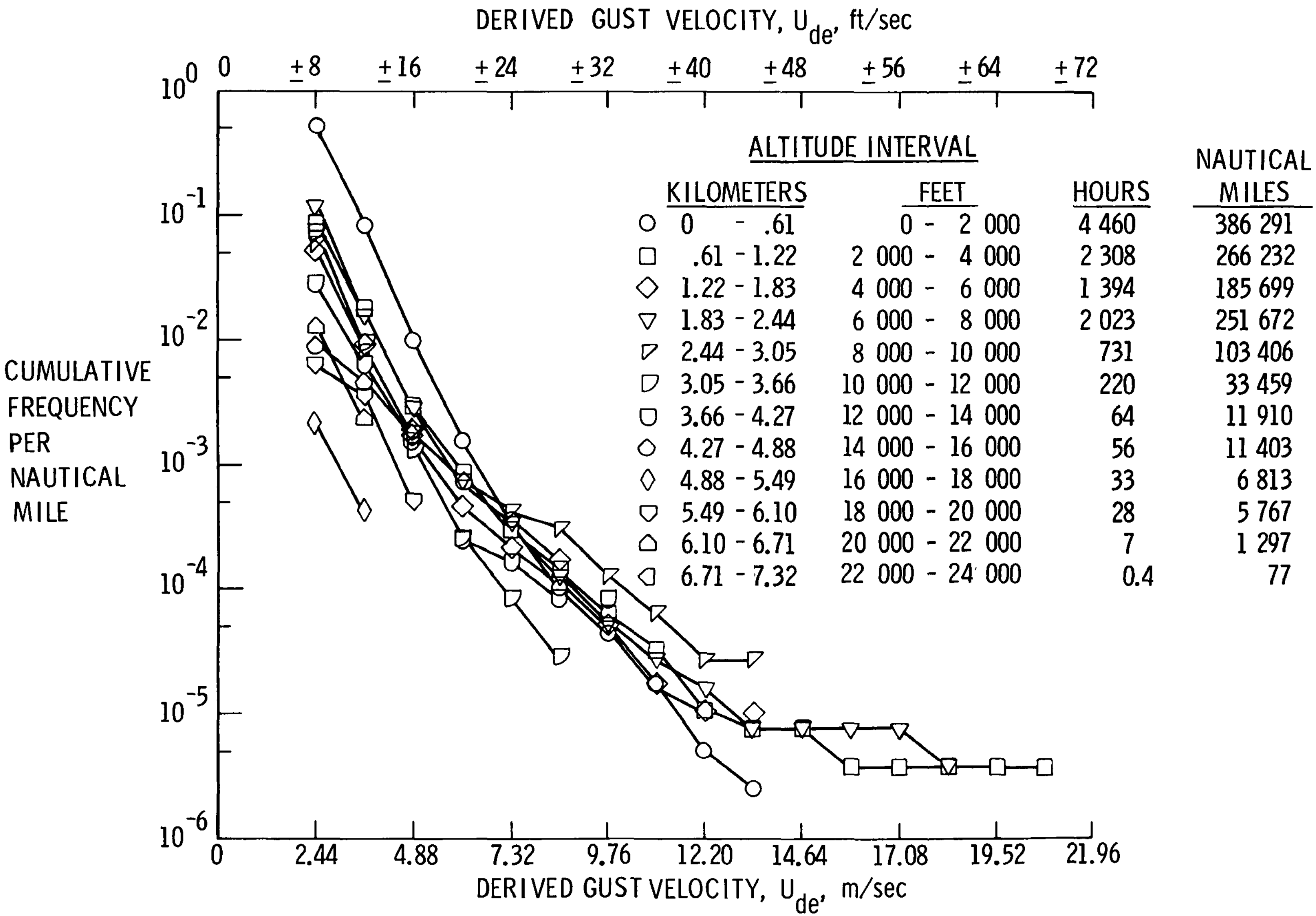
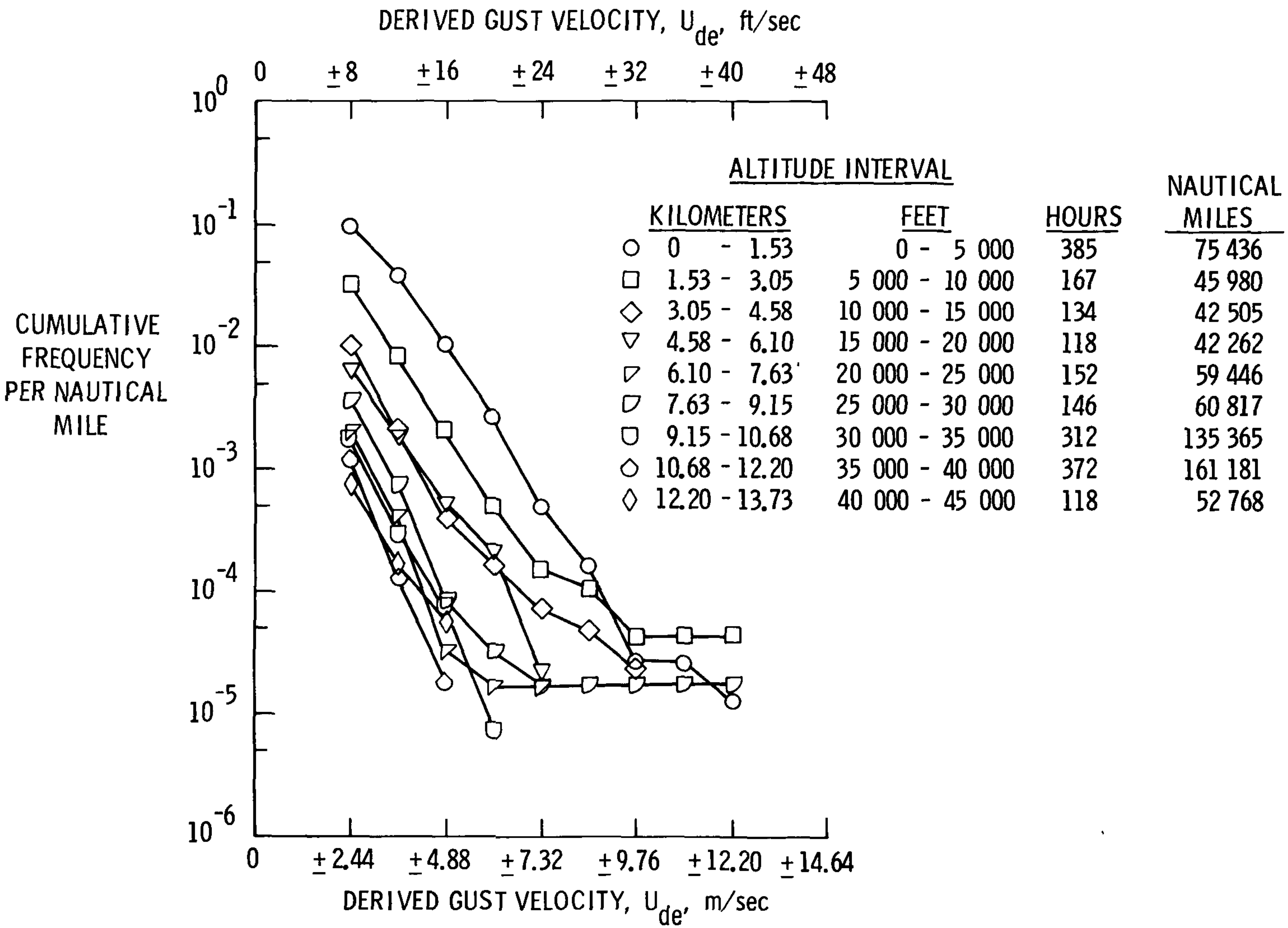
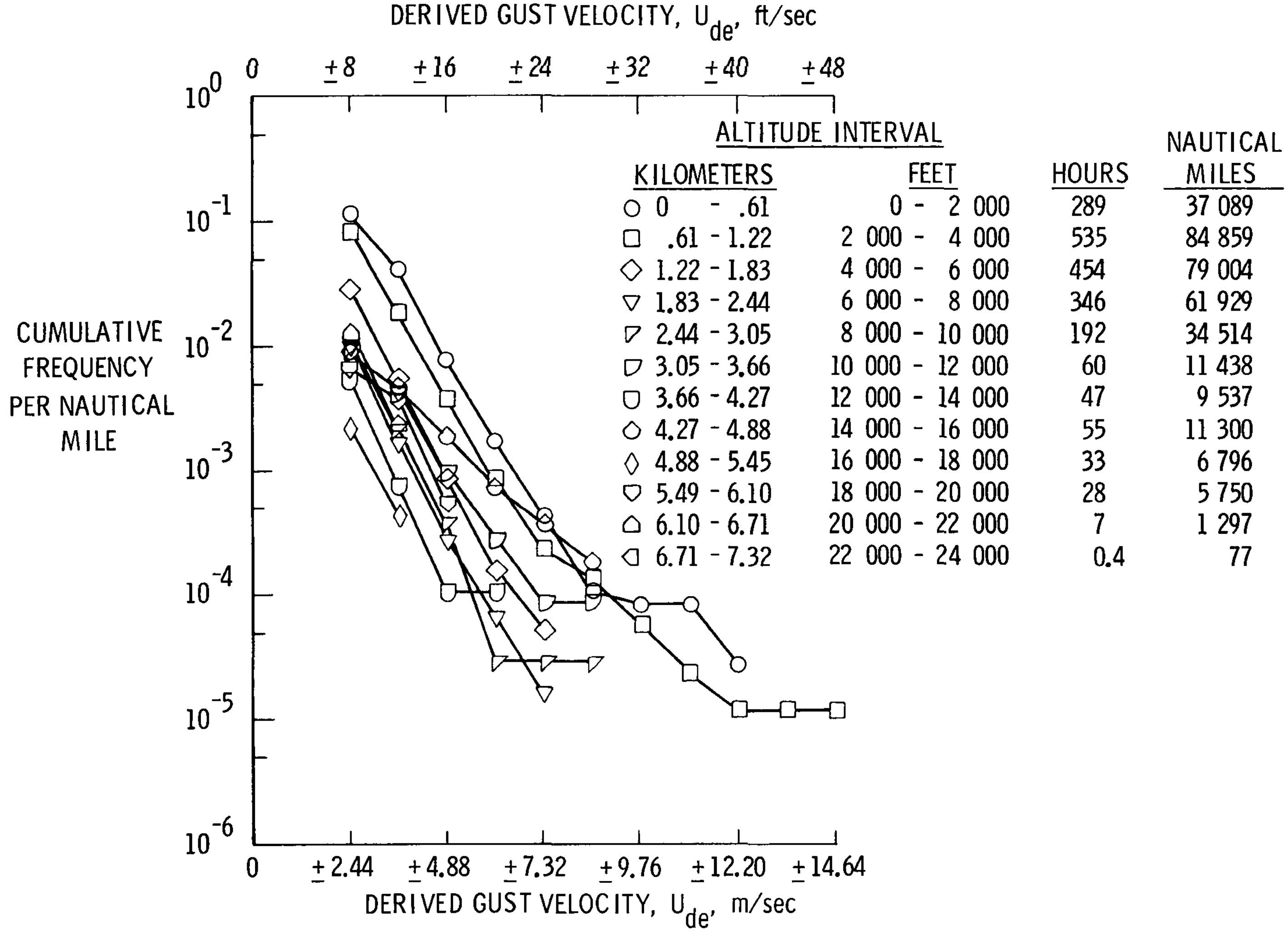


Figure 11.- Variation of derived gust velocities in various altitude intervals for the combined data sample from propeller-driven airplanes.



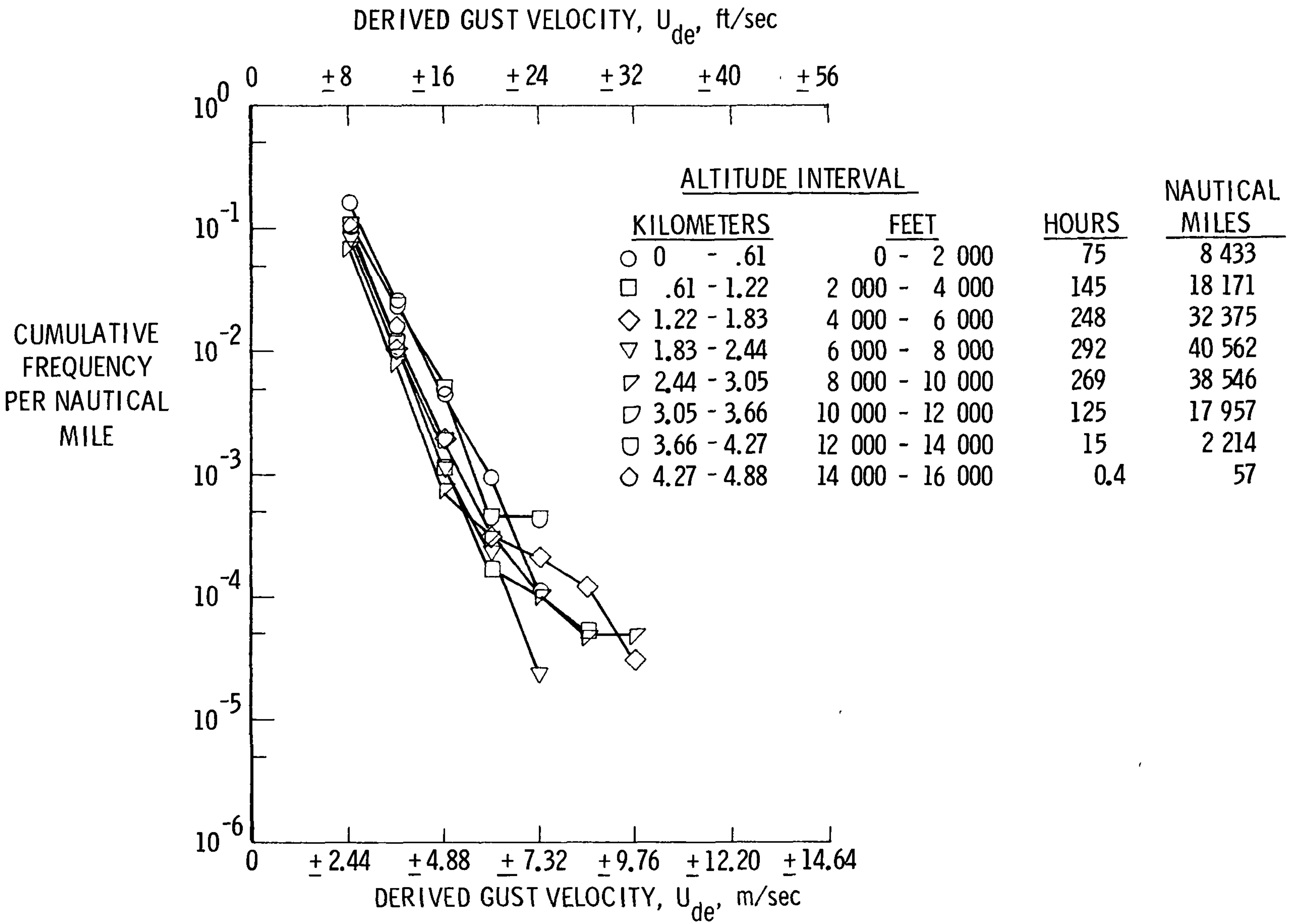
(a) Twin-engine executive – turbojet powered.

Figure 12.- Cumulative frequency of occurrence of derived gust velocities per nautical mile of flight within various altitude intervals for airplanes flown in seven types of operations.



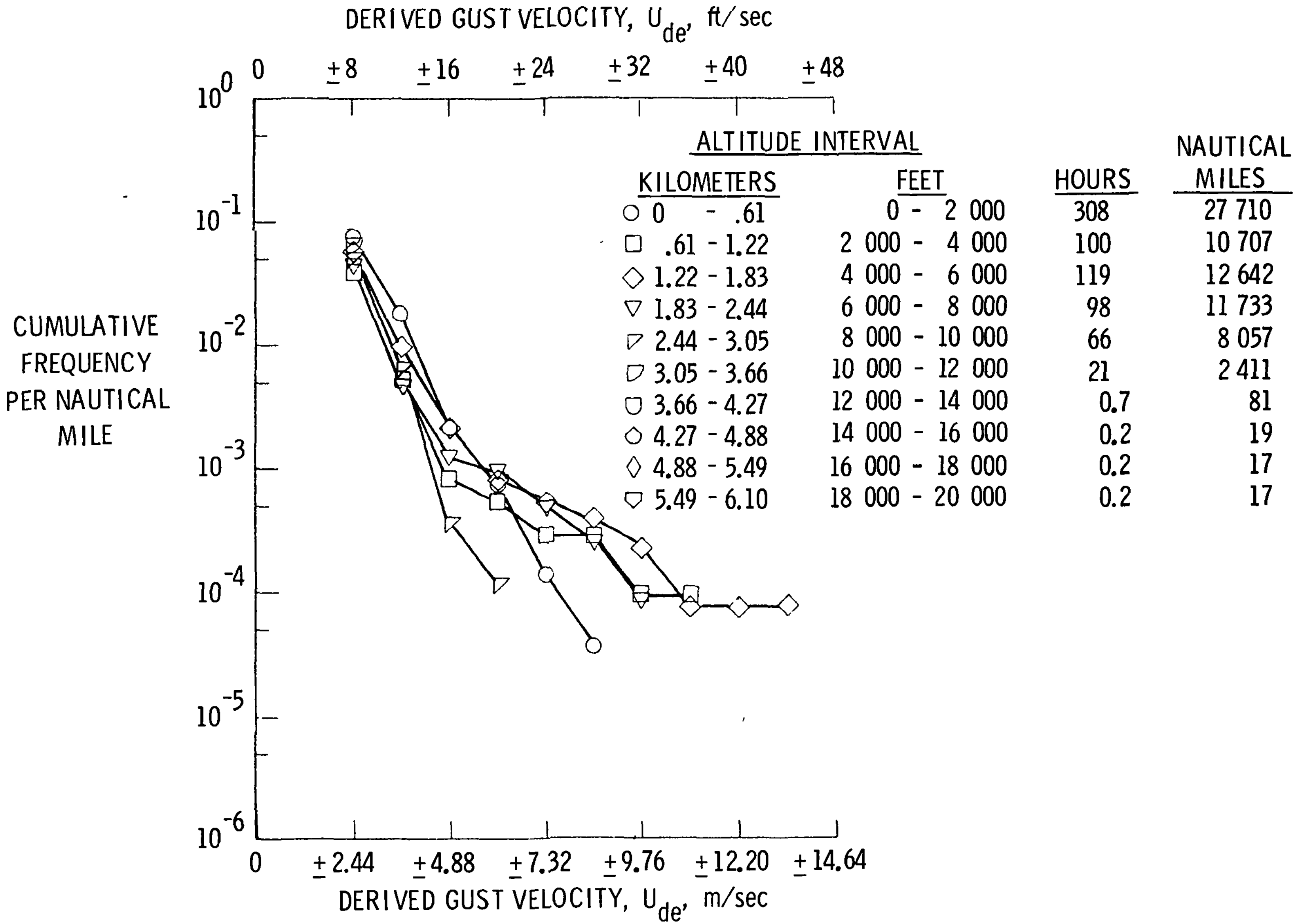
(b) Twin-engine executive – prop driven.

Figure 12.- Continued.



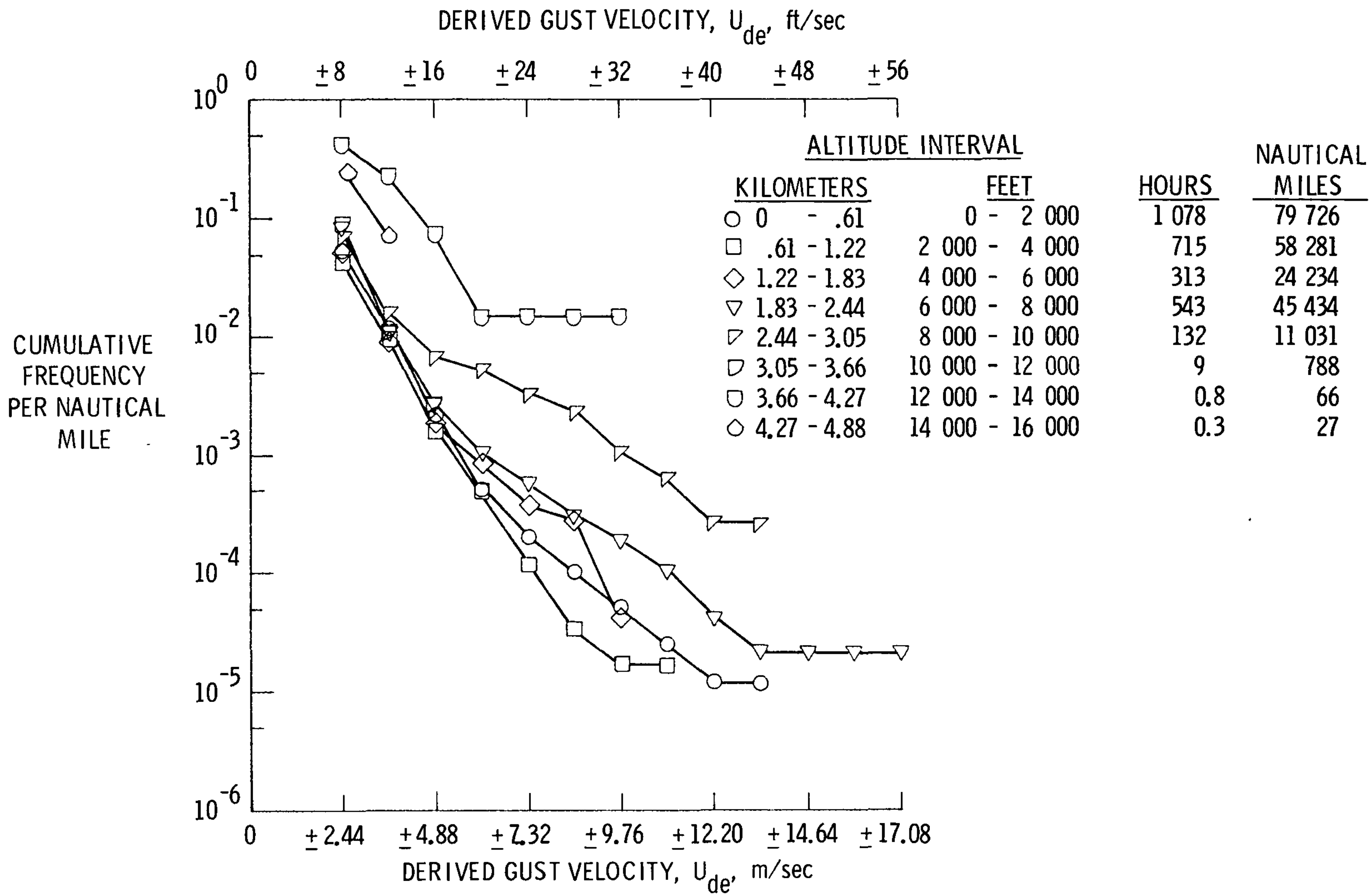
(c) Single-engine executive.

Figure 12. - Continued.



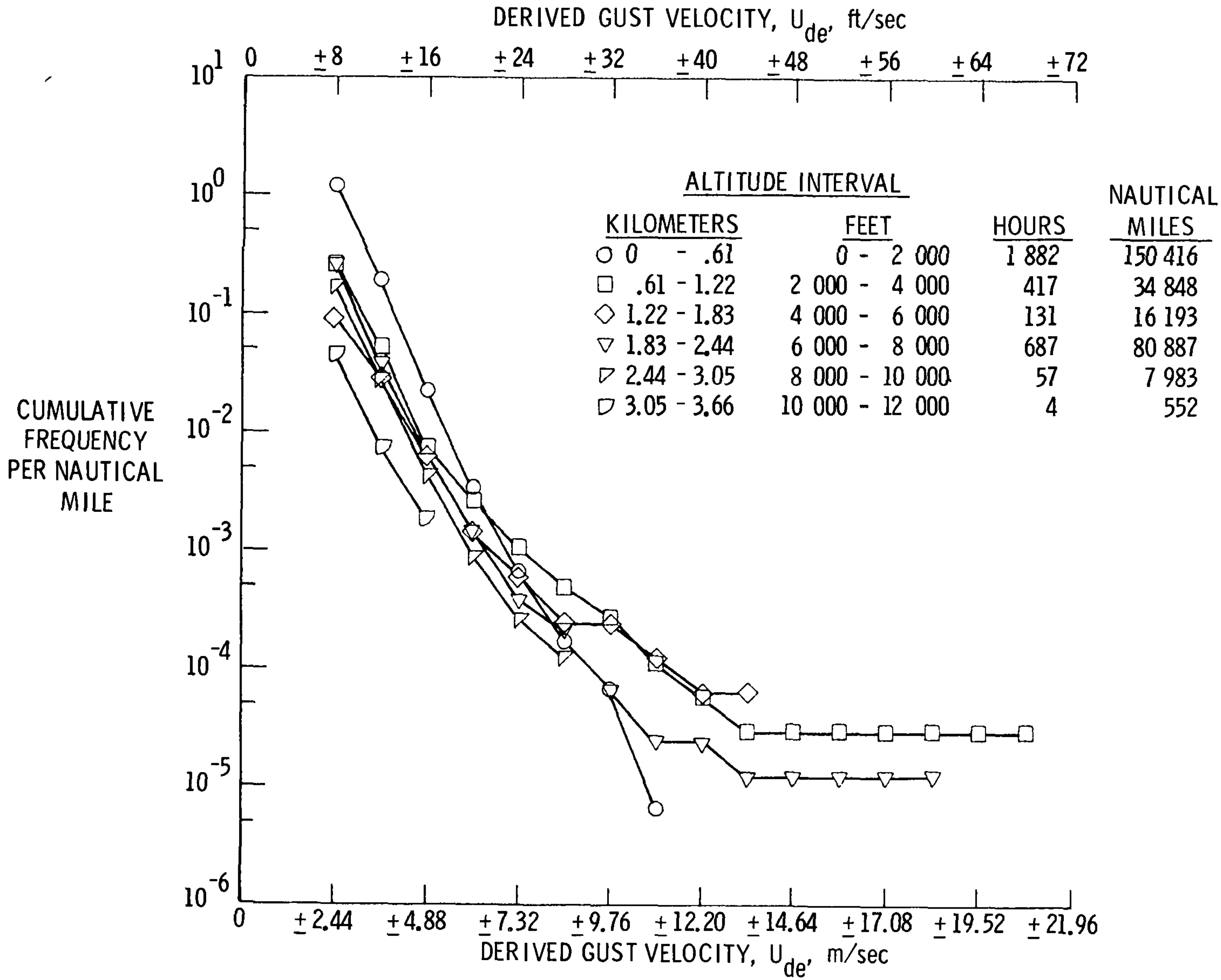
(d) Personal.

Figure 12.- Continued.



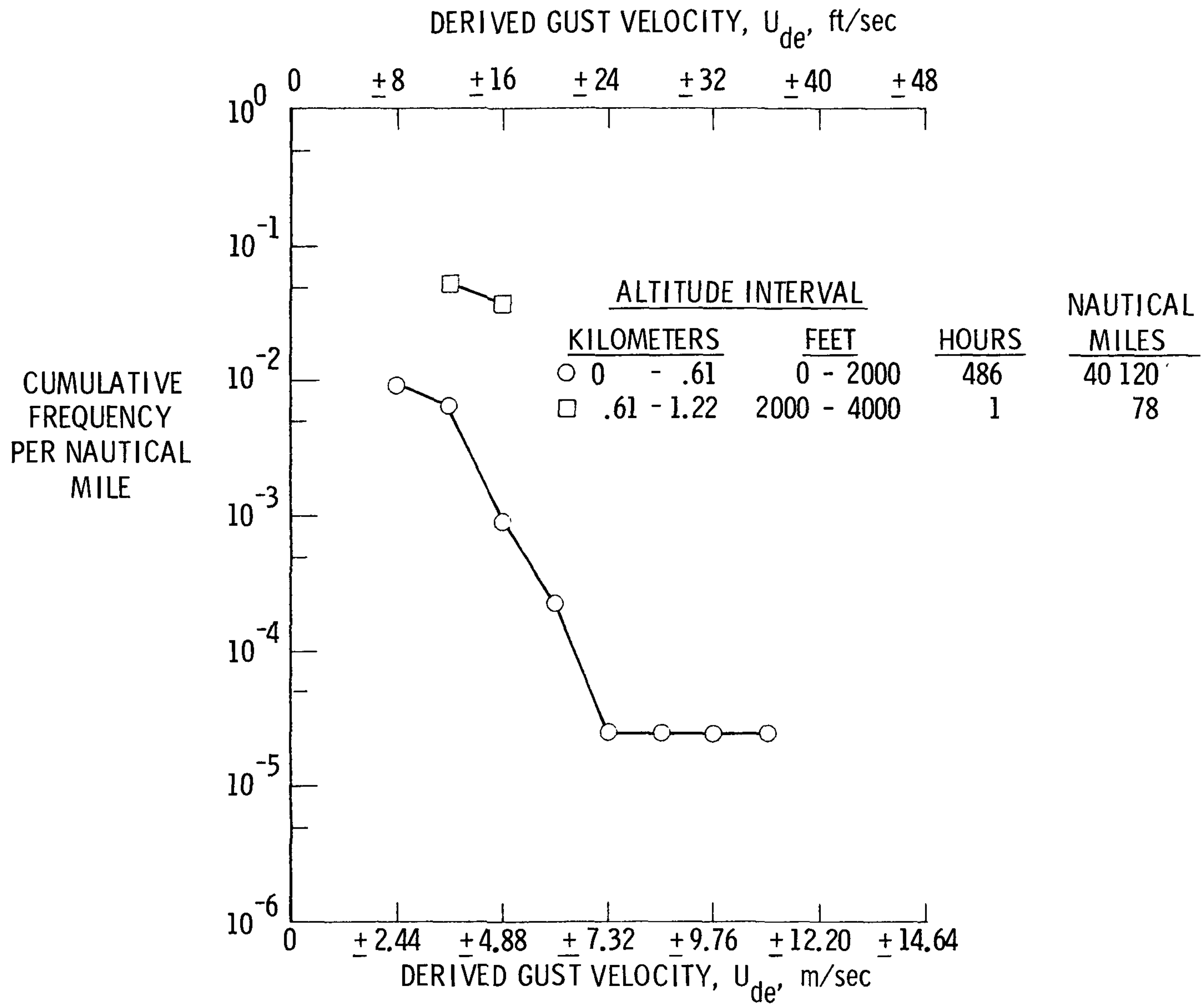
(e) Instructional.

Figure 12.- Continued.



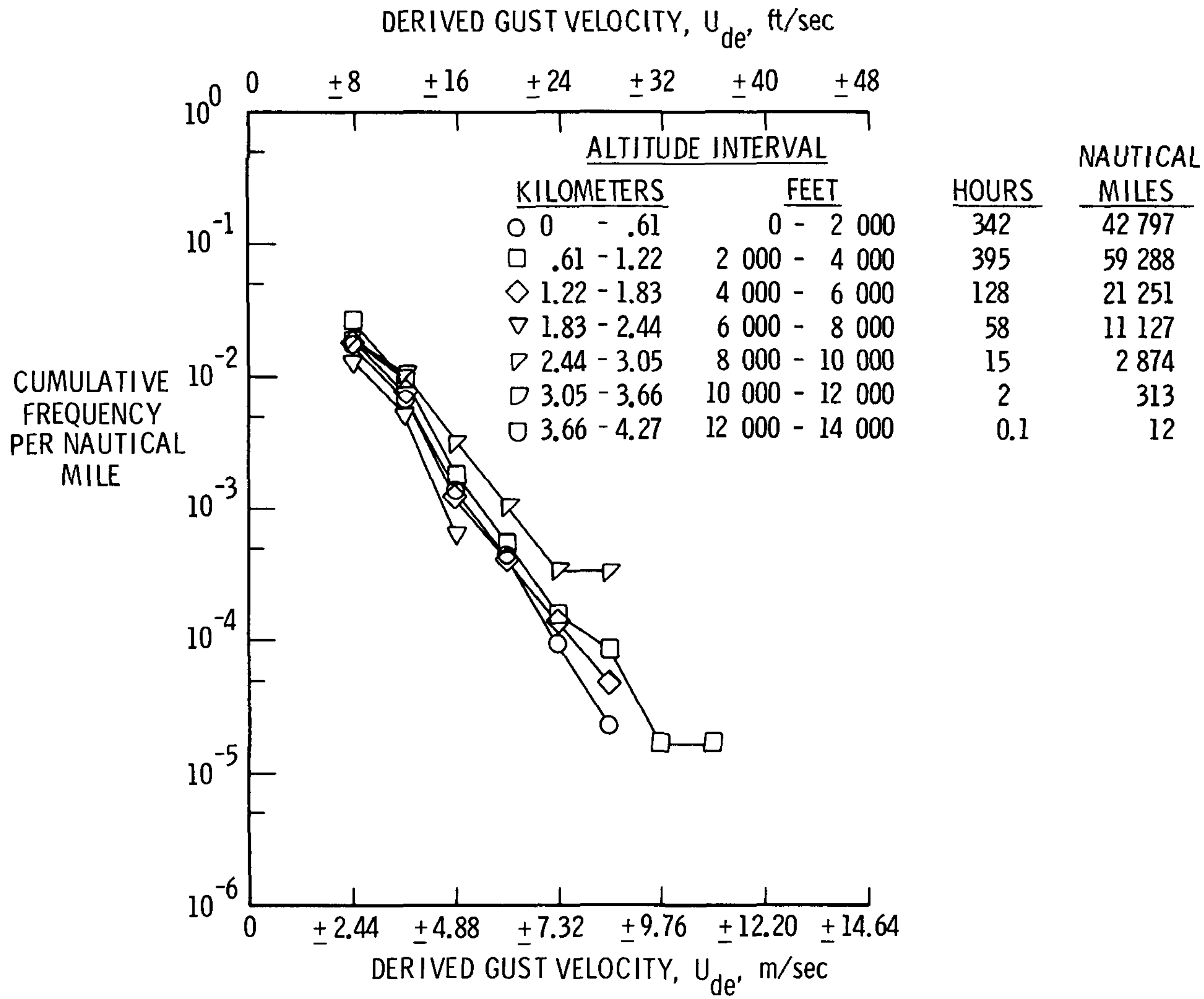
(f) Commercial survey.

Figure 12.- Continued.



(g) Aerial application.

Figure 12.- Continued.



(h) Commuter.

Figure 12.- Concluded.

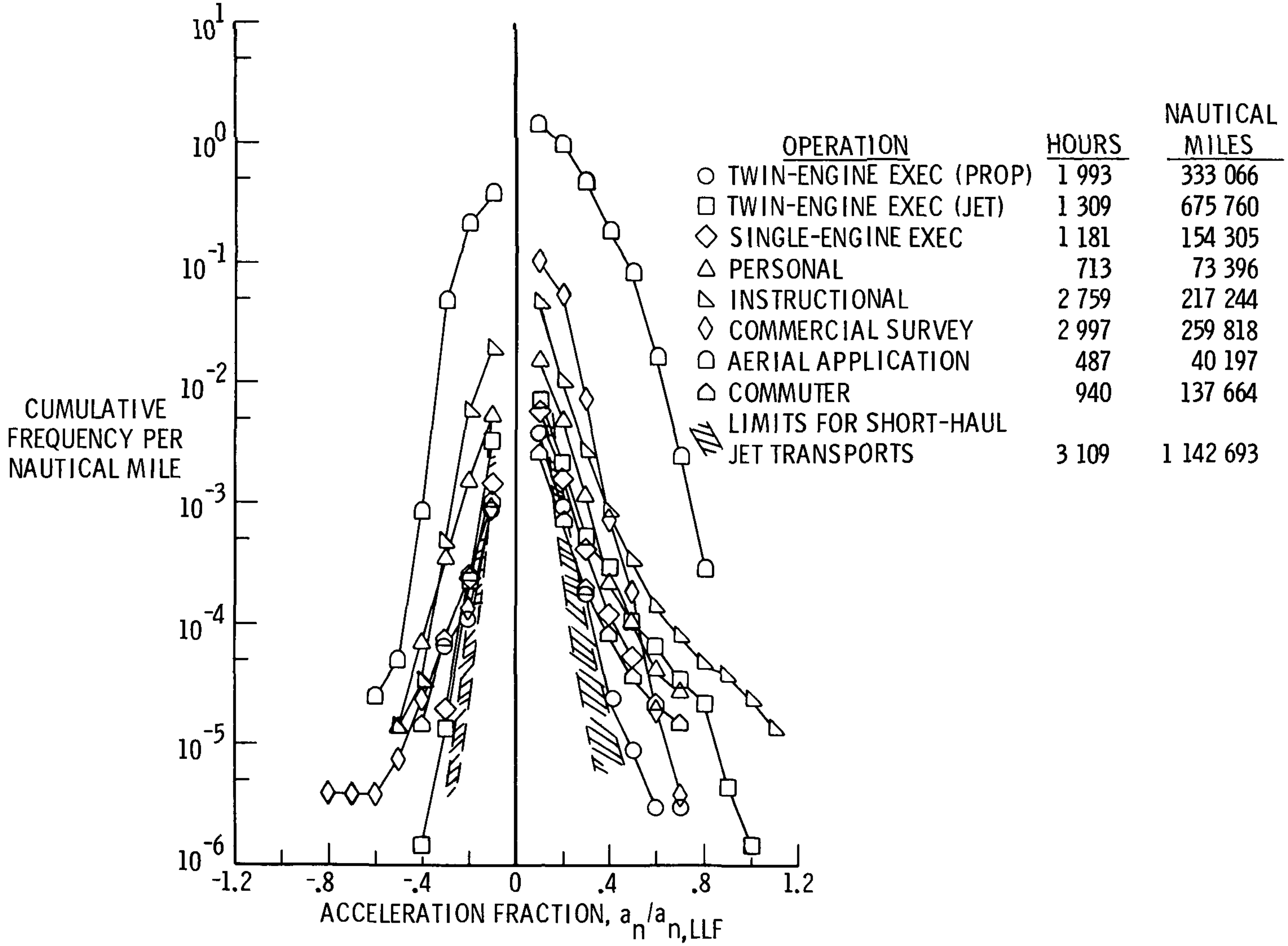
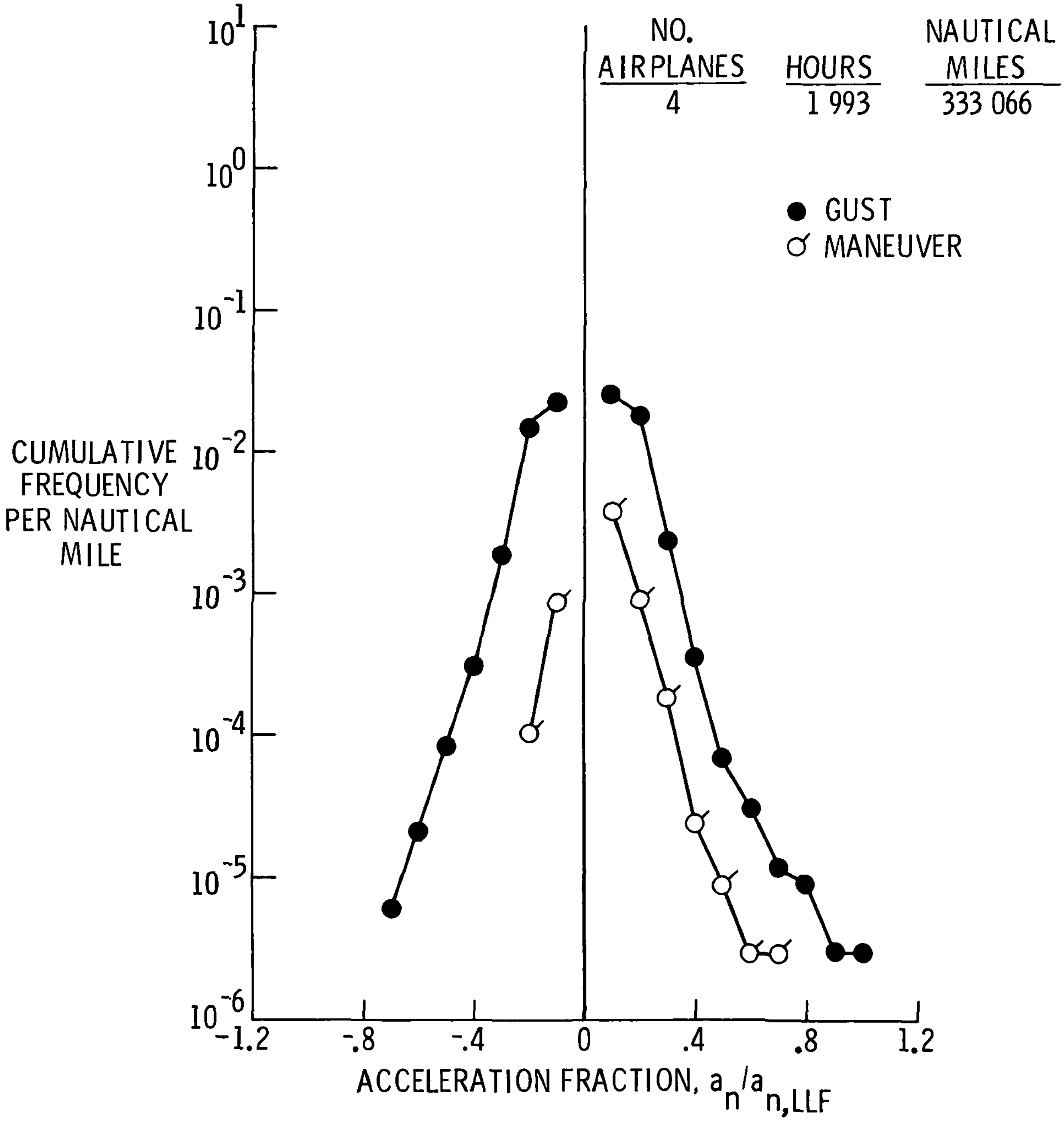
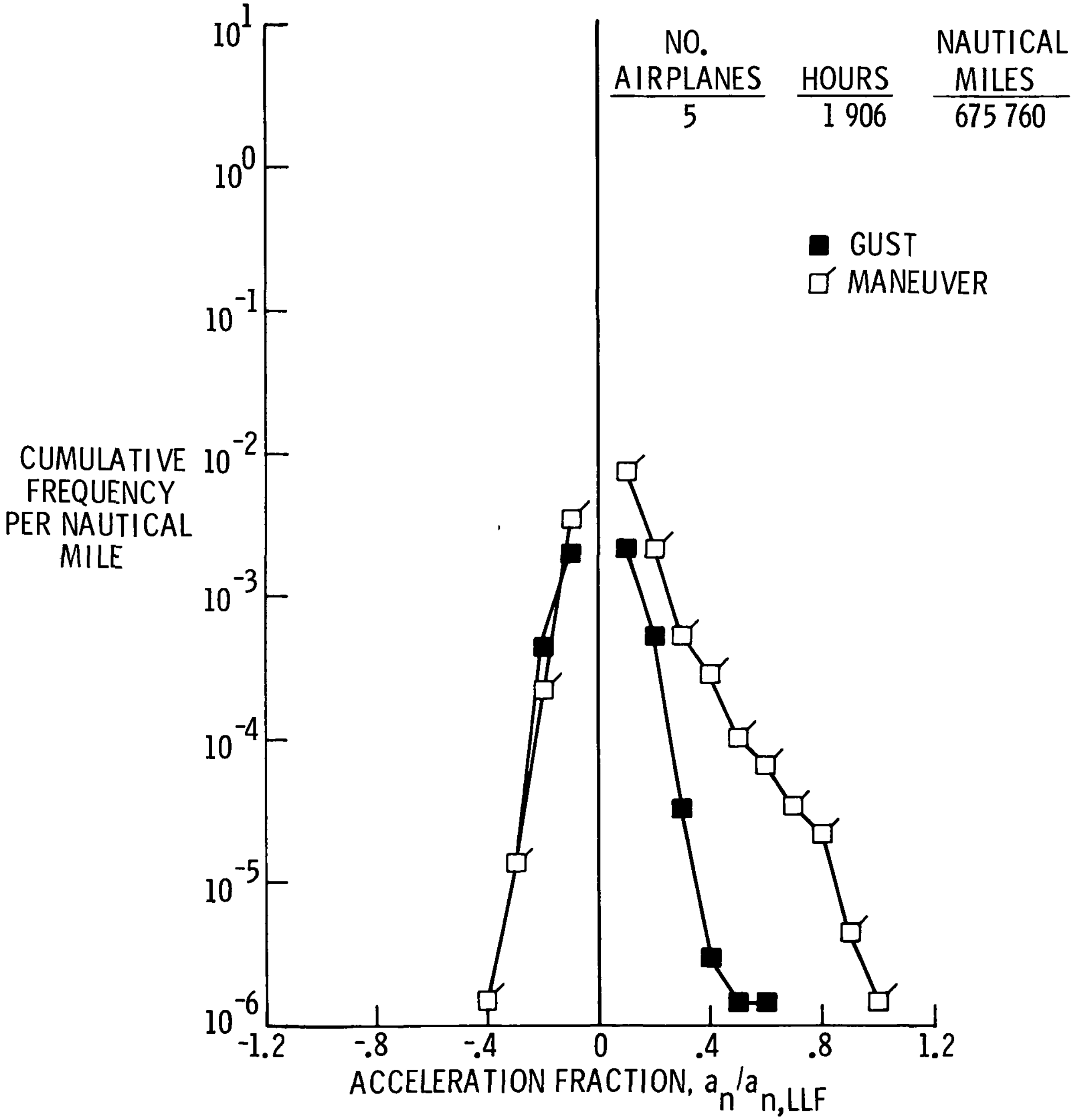


Figure 13.- Comparison of maneuver acceleration fractions experienced during various operations.



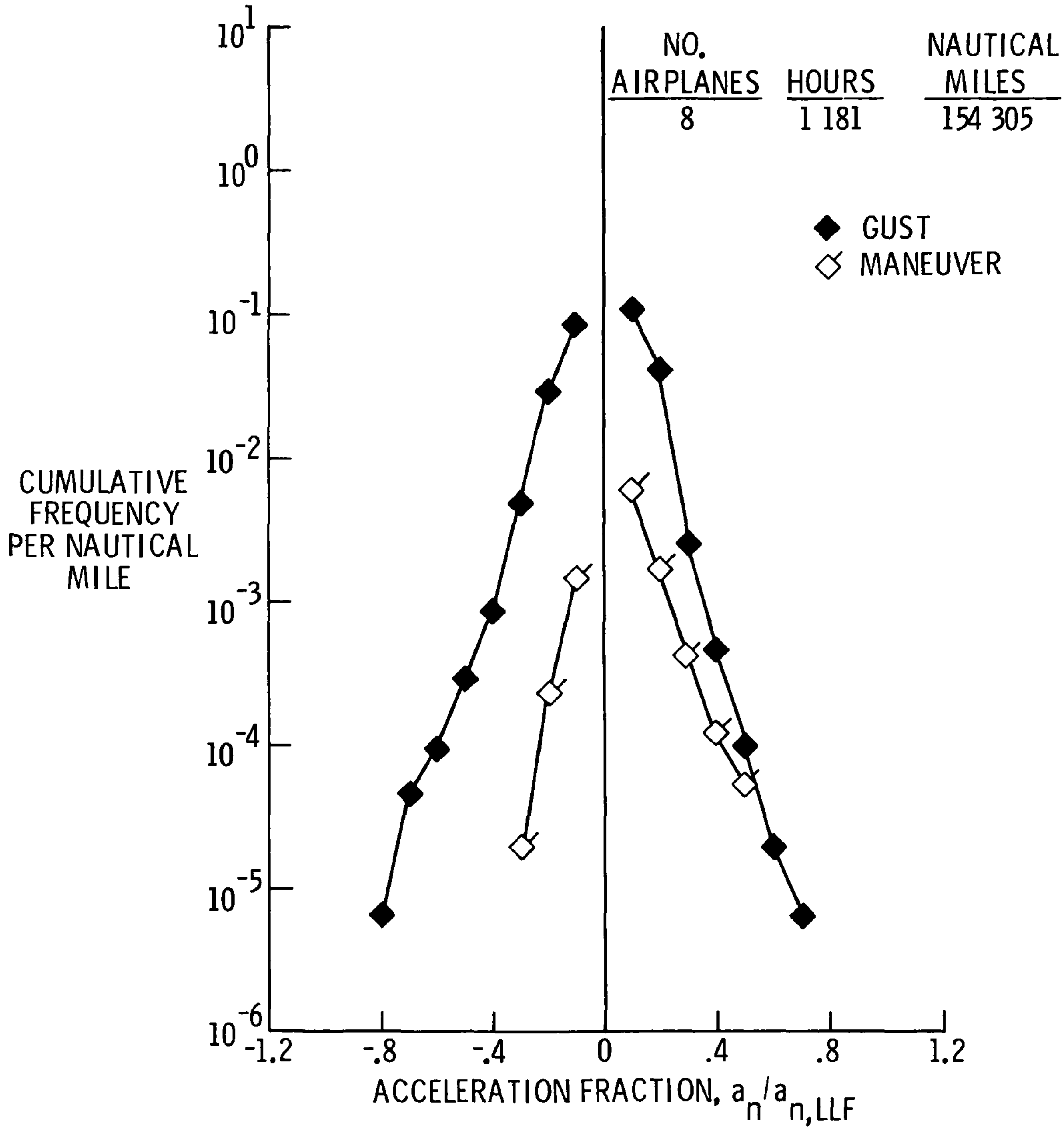
(a) Twin-engine executive – prop driven.

Figure 14.- Comparison of gust and maneuver acceleration fractions experienced during various types of operations.



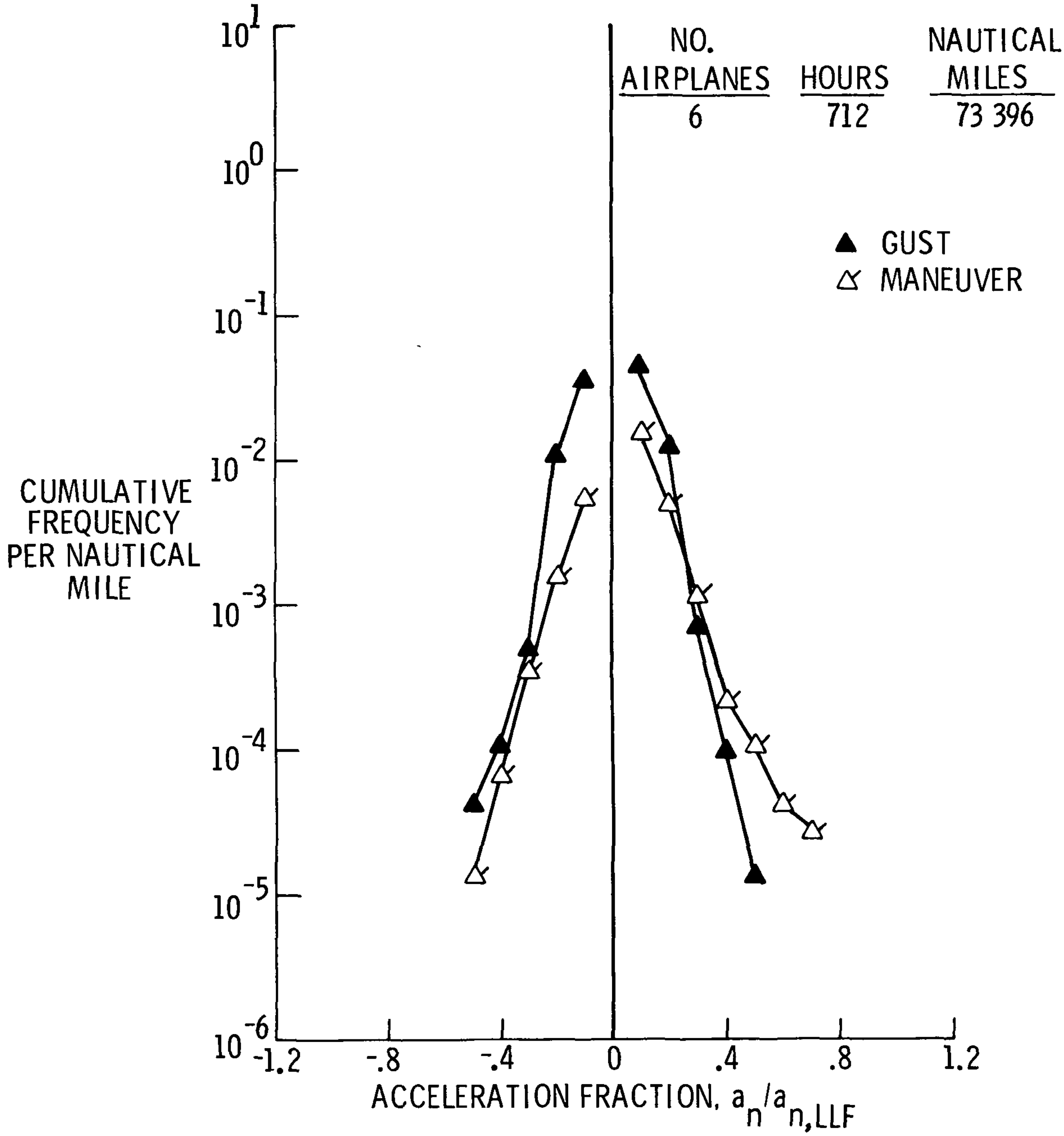
(b) Twin-engine executive – turbojet powered.

Figure 14.- Continued.



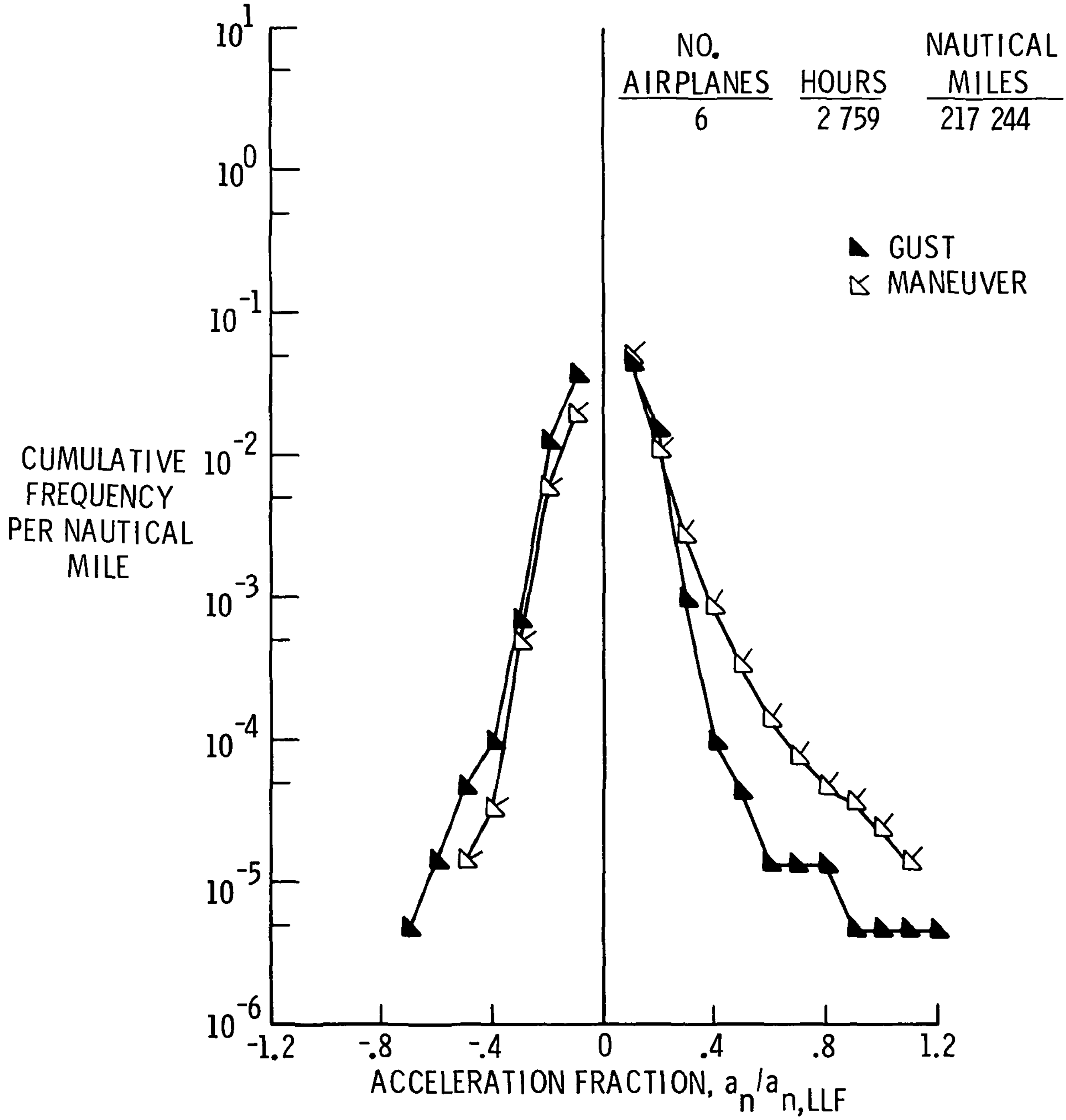
(c) Single-engine executive.

Figure 14.- Continued.



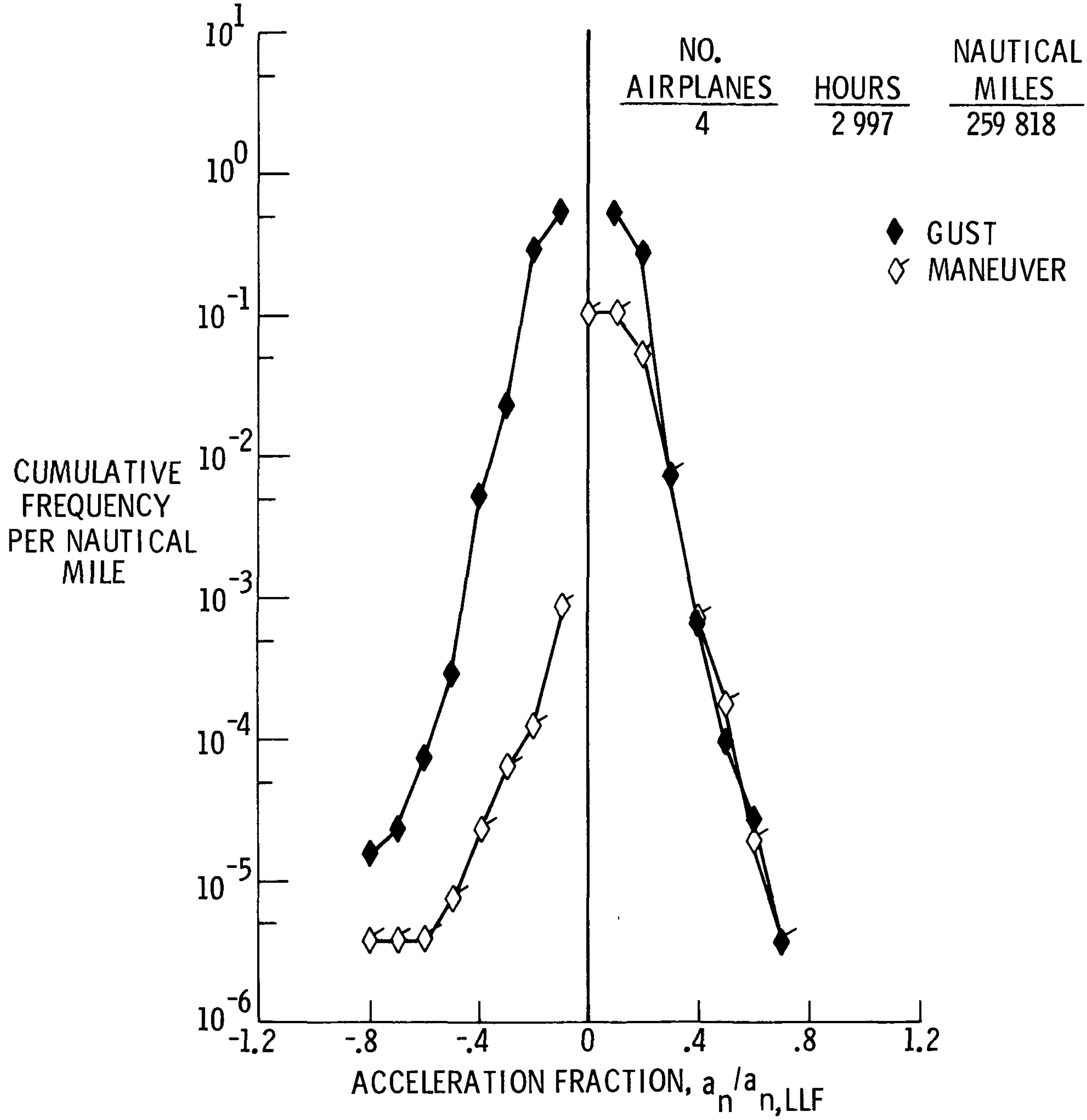
(d) Personal.

Figure 14.- Continued.



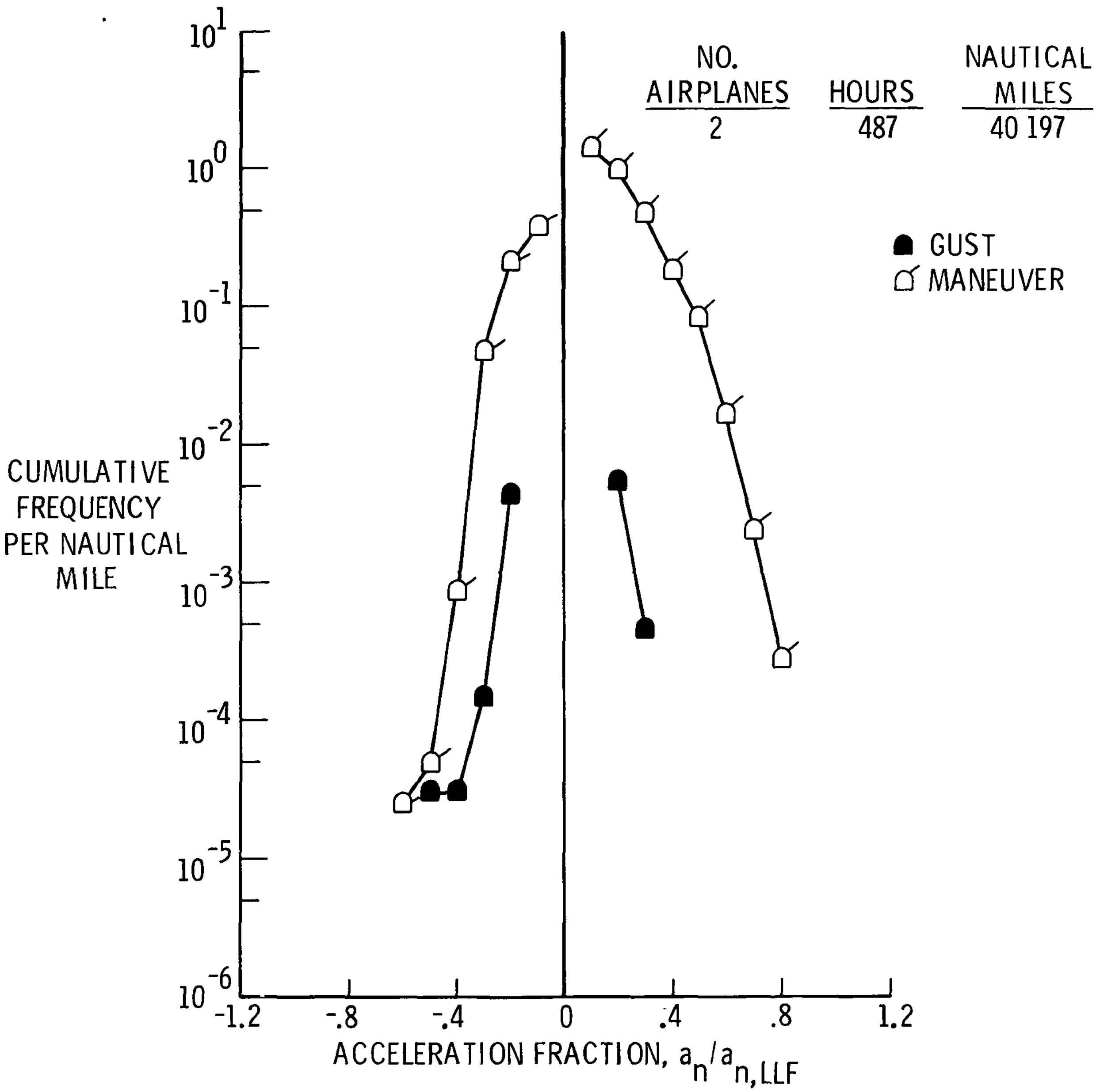
(e) Instructional.

Figure 14.- Continued.



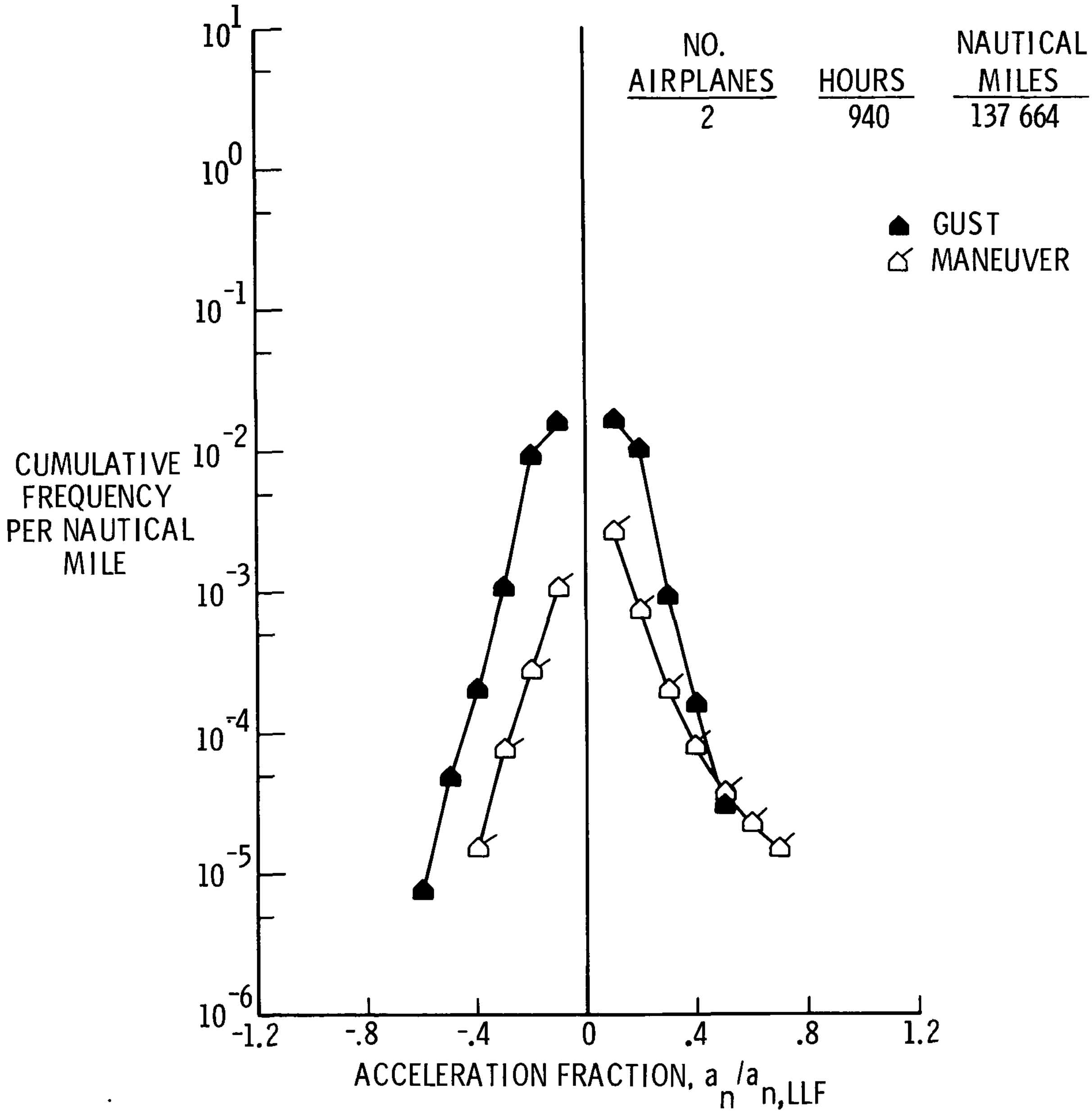
(f) Commercial survey.

Figure 14.- Continued.



(g) Aerial application.

Figure 14.- Continued.



(h) Commuter.

Figure 14.- Concluded.

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