Initial *VGH* Data on Operations of Small Turbojets in Commercial Transport Service

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Initial results obtained from *VGH* (velocity-gravity-height) data collected on seven airplanes representing four types of two- and three-engine turbojet transports during routine operations by six airlines are presented. The information presented relates to the accelerations, airspeed operating practices, and unusual events. The acceleration sources considered are gusts, maneuver, and landing impact. The results indicate that, in general, the gust acceleration, maneuver acceleration, landing-impact acceleration, and gust-velocity experiences are not significantly different from those for past operations of four-engine transports. The differences which do exist are, for the most part, accountable in terms of the airplane characteristics and flight profiles associated with the two classes of airplanes. The average operating airspeeds for the two- and three-engine transports are similar to those for the four-engine transports. The present airplanes show less frequent and smaller margins of overspeeding than was evident during the initial operations of the four-engine transports.

Introduction

As a continuation of its long standing practice of collecting and analyzing statistical operational data on commercial transports (Refs. 1 and 2, for example), NASA is currently sampling operations of several two- and three-engine turbojet transports. Although these programs are not complete as yet, the initial results obtained to date are thought to be of sufficient interest to warrant presentation at this time. Consequently, this paper presents the available information on the operational experiences of four types of two- and three-engine turbojet transports during routine airline operations. The information pertains to the accelerations due to gusts, maneuvers, and landing impacts, and to the airspeed operating practices relative to the structural design and operational placard speeds. The results are compared with previous results on several types of four-engine jet transports.

Instrumentation

Figure 1 shows a photograph of the NASA *VGH* recorder used to obtain the records. The recorder consists of a recorder base, a removable film drum, and a remote acceleration transmitter. The characteristics of the recorder are described in Ref. 3 and will not be discussed herein.

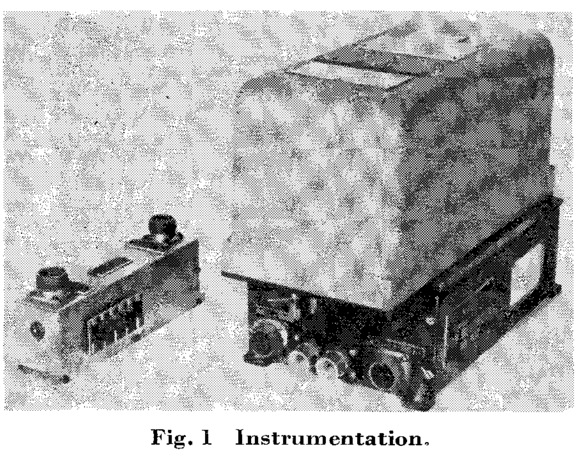

Fig. 1 Instrumentation.

As shown by Fig. 2, the *VGH* record provides time histories of indicated airspeed, pressure altitude, and normal acceleration at the airplane's center-of-gravity. The records were evaluated to obtain frequency distributions of peak incremental accelerations caused by turbulence, maneuvers, and landing impact and to obtain airspeed and altitude distributions. Detailed information concerning the *VGH* record evaluation procedures are given in Ref. 2.

Scope of Data

Airplanes

The airplanes on which the data were collected are described in Table 1 in terms of the gross weight, wing loading, wing sweep, and the number of engines. Airplane types I, II, and III are twin-engined, have gross weights that range from 76,000 to 110,000 lb, wing loadings of about 70 to 98 psf, and wing sweep from 20 to 24°. Airplane type IV has three engines, a gross weight of 152,000 lb, $W/S = 92.1$, and 32° wing sweep. Airplane types I and II are foreign built, whereas types III and IV are manufactured in the U.S. Although airplane type I has been in domestic U.S. service for about five years, the data included herein represent the initial *VGH* sample from that type.

In contrast to the four-engine jet transports, the two- and three-engine transports have much lower gross weights, and generally have lower wing loadings and less wing sweep.

Airlines and Sample Sizes

As shown in Table 2, the data were collected on six airlines which include three foreign and three U.S. operators.

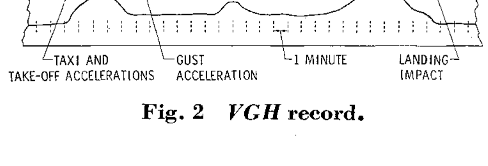

Fig. 2 *VGH* record.

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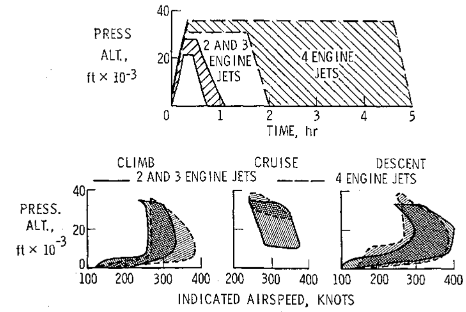

Fig. 3 Flight profiles.

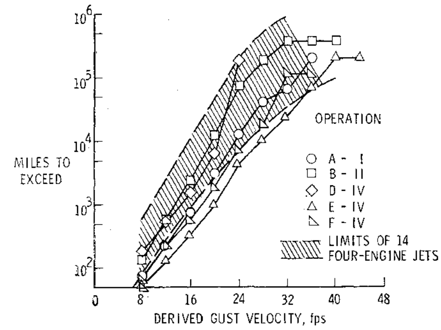

Fig. 5 Derived gust velocities.

One airline is represented in each of the data samples for airplane types I, II, and III, whereas data are available from three operators of the type IV airplane.

The individual airline data samples range in size from about 180 to 1150 flight hours. The data sample from airplane III is too small to provide adequate reliability for many phases of the analysis, and, consequently, only overspeed data will be presented from this sample.

Results

Description of Operations

Inasmuch as some of the results to be presented are influenced by the airplane flight profiles, a brief comparison of average flight profiles for the two- and three-engine jet transports with those for the four-engine transports is given in Fig. 3. The flight profiles are given in terms of the altitude as a function of flight time (upper plot) and the indicated airspeed as a function of flight condition (lower plot). The envelopes in the lower plot represent actual airspeed-altitude variations for several airplanes within each class. In each plot the envelopes of the average flight profiles for the small jets and the four-engine jet transports are given. The comparison shows that the flight durations for the small jets average about 1 hr in contrast to the 2- to 5-hr flight durations for the big jets. Average cruise altitudes for the small jets range from 20,000 to 28,000 ft in contrast to the 30,000 to 35,000 ft altitude for the four-engine jets. Also, the small jets spend only about 50% of the total flight time in cruise, whereas the big jets spend about 75% of the time in cruise. The lower plot shows that, except for somewhat lower speeds in climb for the small airplanes, the average indicated speeds for the classes of airplanes are not appreciably different. Thus, the major differences between the flight profiles for the two classes of airplanes are the shorter flight durations, the lower cruise altitudes, and a smaller percentage of total flight time in cruise for the two- and three-engine jets.

Turbulence

Amount of rough air: The amount of rough air experienced in the various operations is shown in Fig. 4. For each operation, the percent of the total flight time which was spent in rough air is plotted at the average over-all altitude for the operation. Also shown is the amount of rough air encountered, on the average, by the four-engine transports. For this presentation, rough air is defined as any patch of turbulence containing derived gust velocities larger than approximately 2 fps.

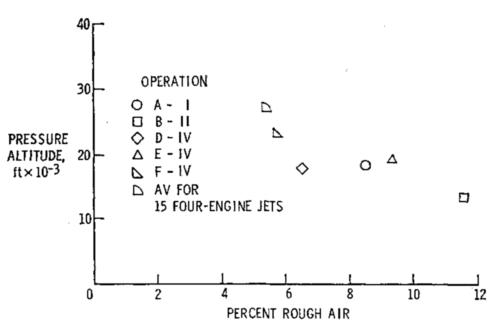

Fig. 4 Rough air experience.

The results in Fig. 4 show that the percent of total flight time spent in rough air by the two- and three-engine transports ranges from about 5.7 to 11.5%. Thus, these transports spend roughly twice as much time in rough air as do the four-engine transports. The reason for this is that because of the shorter flights and lower cruise altitude, a higher percentage of the total flight time is spent at the lower altitudes where rough air is more prevalent.

Gust-Velocity Experience

The gust-velocity experiences for the various operations are shown in Fig. 5 in terms of the average flight miles required to exceed a given value of derived gust velocity. The derived gust velocities were computed from the simultaneous values of gust acceleration, airspeed, and altitude read from the *VGH* records together with pertinent values for the airplane wing loading and lift-curve slope. For comparison with the present results, the range of the gust-velocity distributions for four-engine jet transports is shown by the hatched area.

For values of gust velocity less than about 20 fps, the results show differences of about 10:1 among the flight miles to exceed given values of gust velocity for the various operations. Somewhat larger variations are noted at the higher values of gust velocity. Such differences among the gust experiences of various operations are not unusual, and may be attributed to real differences among the turbulence environments associated with the different airlines, airline operational practices as regards turbulence avoidance, and to low statistical reliability because of small sample size.

In general, the gust experiences for the present airplanes lie within or slightly on the severe side of the envelope of gust experiences for the four-engine transports. Thus, while the data do not show a significant difference between the gust experiences for the two classes of airplanes, there is an indication that, on the average, the gust experience for the

Table 1 Airplane characteristics

Airplane type	Gross wt, lb	Wing loading, psf	Wing sweep, deg	No. of engines
I	110,000	69.8	20	2
II	76,000	78.1	20	2
III	90,700	98.1	24	2
IV	152,000	92.1	32	3
Range for four-engine jets	184,000 to 315,000	92.3 to 113.7	30 to 35	4

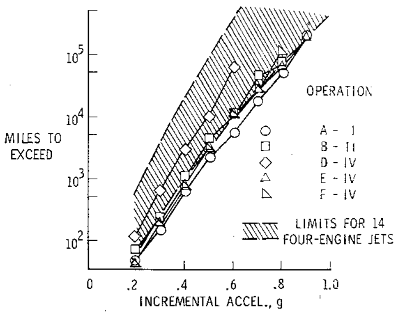

Fig. 6 Gust accelerations.

two- and three-engine transports may be slightly more severe than that for the four-engine airplanes. This is attributed primarily to the differences between the average operating altitudes for the two classes of airplanes.

Gust Accelerations

The gust-acceleration experiences for the various operations are shown in Fig. 6 in terms of the average flight miles required to exceed given values of incremental acceleration. The range of corresponding results for four-engine transports is also shown by the hatched region. Differences of about 5 to 1 are evident among the flight miles to exceed given values of acceleration for the various operations. These differences are due mainly to the differences among the airplane characteristics and the flight profiles. For example, the most severe acceleration experience (A-I) is for the airplane with the lowest wing loading and with the least sweep—both factors which tend to cause high gust response. Similarly, the less severe acceleration experience (D-IV) is for the airplane having the highest wing loading and the most wing sweep. The accelerations for Operations E-IV and F-IV are similar to those of Operation A-I; but the gust velocities for those operations, shown in Fig. 5, were somewhat higher than those for Operation A-I.

The acceleration experience for the two- and three-engine transports lies within the more severe half of the range shown for the four-engine transports. This is due to the combined effects of the slightly increased exposure to rough air and to the higher gust-response characteristics of the two- and three-engine transports. It is cautioned that, because airplanes are designed to different gust loads depending upon their particular characteristics, the results in Fig. 6 do not provide a direct comparison of the structural loads imposed on the different airplanes.

Maneuver Accelerations

The accelerations due to airplane maneuvering may be conveniently classed according to the purpose of the flight during which they occurred. Thus, the maneuvers which are performed during routine passenger-carrying flights are designated as being "operational maneuvers." Those which occur during airplane or pilot training and check flights are designated "check-flight maneuvers."

Table 2 Airlines and sample sizes

Airplane type	Airline	Location	Sample size, hr
I	A	U.S.	612
II	B	U.S.	1156
III	C	Foreign	176[a]
IV	D	U.S.	461
IV	E	Foreign	533
IV	F	Foreign	346

[a] Only overspeed data available.

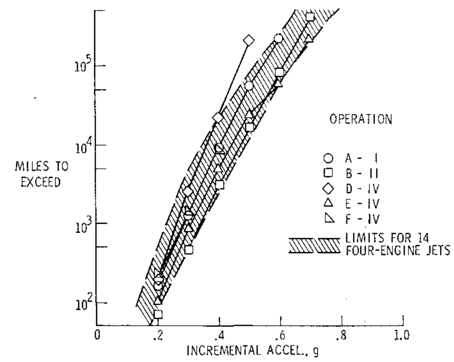

Fig. 7 Operational maneuver accelerations.

The average flight miles to exceed given values of operational maneuver accelerations are shown in Fig. 7. Again, corresponding results for four-engine transports are shown for comparison. The results show differences of about 5 to 1 among the flight miles to exceed a given value of operational maneuver acceleration for the various operations. Such differences have been noted in the past among operations of both piston- and four-engine jet transports, and are thought to be due to differences among route structure and airline practices regarding flightpath and heading changes. The operational maneuver experiences for the present airplanes do not appear to be significantly different from those for the four-engine transports.

The check-flight maneuver acceleration experiences are shown in Fig. 8 in comparison with the range of results for the four-engine transports. Based on the available data samples, differences of about 1000 to 1 exist among the check-flight maneuver acceleration experiences of the present airplanes. As shown in the figure, the amount of time spent in check flights range from about 0.7% of total flight for Operation F-IV to 8.5% for Operation D-IV. This accounts for part of the large variations in the check-flight maneuver acceleration experiences. Probably a more dominant factor, however, is the sampling reliability. In this regard, past work has shown that much larger data samples than are presently available are required to provide good estimates of the check-flight maneuver acceleration experience. Nevertheless, the results for four of the five operations are in fair agreement with the range of results for the four-engine transports. Consequently, at this time there is no strong indication that the check-flight maneuver acceleration experiences for the two- and three-engine transports will differ significantly from that for past operations.

Comparison of Gust and Maneuver Accelerations

As an indication of the relative importance of gust and maneuvers to the total in-flight acceleration experience, the distributions of acceleration caused by gusts, operational maneuvers, and check-flight maneuvers for one operation (B-II) are shown in Fig. 9. The results show that accelera-

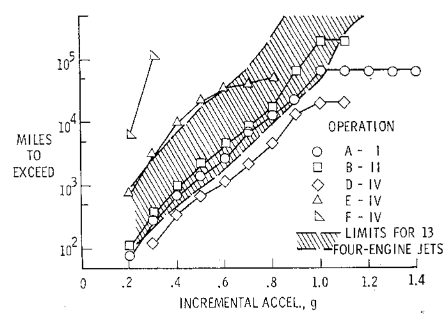

Fig. 8 Check-flight maneuver accelerations.

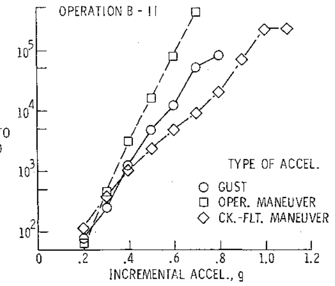

Fig. 9 Comparison of accelerations.

tions less than about 0.4 g occurred with roughly equal frequency from the three sources. Check-flight maneuvers were the predominant source of accelerations higher than 0.4 g and accelerations caused by operational maneuvers were the least frequent. These results are representative of the results for three of the operations of the two- and three-engine transports and are similar to the results obtained on four-engine jet transports. For Operations E-IV and F-IV, for which check-flight maneuver experience was mild, gust accelerations were predominant at all levels of acceleration.

Landing Impact Accelerations

Figure 10 gives a comparison of the landing impact accelerations of the two- and three-engine transports. The curves show the probability that a landing will result in an acceleration larger than a given value. The data shown for airplane type II were obtained subsequent to a modification made to the original landing gear configuration. The results show that the landing impact accelerations for the five operations were very similar. Comparison of the three distributions for airplane type IV shows that they are also very similar and that there were no appreciable effects of operator on the landing impact accelerations for this type of airplane.

The landing impact acceleration experience of airplane type II which was previously shown in Fig. 10 is compared in Fig. 11 with acceleration data obtained during the operation of the airplane prior to the modification of the landing gear. The accelerations of the initial sample were higher than those of any of the other airplane types sampled and were about 60 to 70% higher than those obtained subsequent to the landing gear modification. The modification consisted of adding weights to the landing gear to change the frequency response.

Airspeeds

Figure 12 shows the average indicated airspeed within each 5,000-ft-altitude interval for each of the operations. For comparison, the maximum operating limit speed V_{MO} and the maximum operating Mach number M_{MO} are also shown in the figure. For each airplane and operation, the average speeds are substantially lower than the V_{MO} speeds throughout the altitude range. In general, the margins between the average speeds and the V_{MO}, M_{MO} speeds decreased with increasing altitude. The relationships of the average speeds to the V_{MO}, M_{MO} speeds shown in Fig. 12 for the present air-

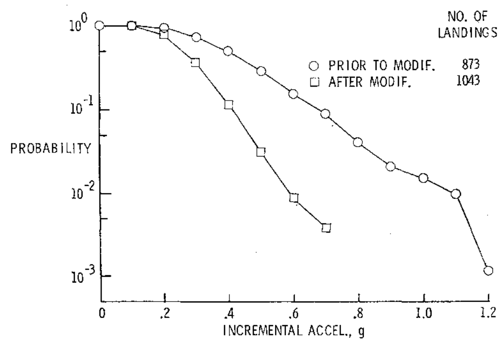

Fig. 11 Effect of landing gear modification on landing impact accelerations of type B-II airplanes.

planes are quite comparable to those associated with four-engine jet transport operations.

Past analyses of transport airspeed data have shown that the placard V_{MO}, M_{MO} speeds are occasionally exceeded. This was particularly the case immediately following the introduction of the four-engine jet transports. Information on the exceedances of the placard speeds by the two- and three-engine transports is given in Fig. 13. For each airplane type, the data show the maximum airspeed and the corresponding altitude for each exceedance of V_{MO} + 6 knots or M_{MO} + 0.01. The 6 knots and 0.01 Mach number increments above V_{MO} and M_{MO}, respectively, were taken to represent the margin on the overspeed warning bell which is permitted by the Federal Air Regulations.

For airplane types I, II, and III, the results in Fig. 13 show that exceedances of V_{MO} speeds up to about 13 knots have occurred in the limited data samples examined. These overspeeds have all occurred in the lower altitudes where the airplanes are airspeed limited rather than in the Mach limited range. No overspeeds have been noted on airplane type IV in the 422 flights by two operators which have been examined. For the present airplanes, the placard speed exceedances appear to be less frequent and the speed exceedances to be smaller than those which were recorded following the introduction of the four-engine jet transports. It should be noted that for the initial operations of the four-engine jets, the warning bell was installed to operate at the placard never-exceed speed V_{NE} which was generally appreciably higher than the currently used V_{MO} + 6 knots.

Unusual Occurrences

During the first few years of operations of the four-engine turbojets, a number of unusual occurrences were noted on the *VGH* records. These took such forms as large flight-path deviations during climbout and landings, loss of control following upset in turbulence, continuous longitudinal oscillations due to autopilot/control system characteristics, and operations outside the normal airspeed-altitude-weight envelope. Except for an occasional indication of a low-

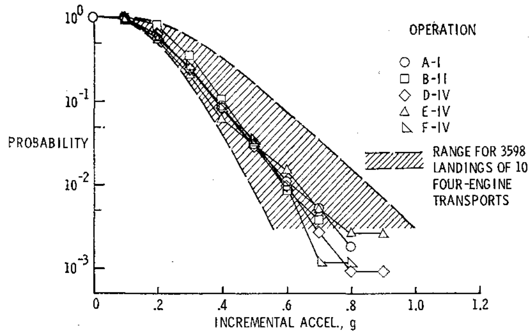

Fig. 10 Landing impact accelerations.

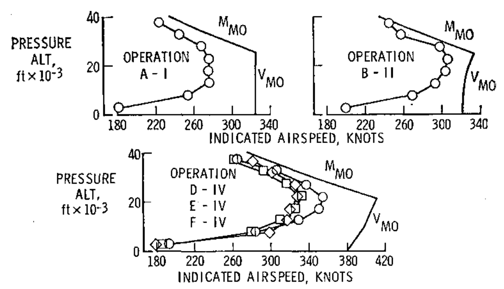

Fig. 12 Average airspeeds.

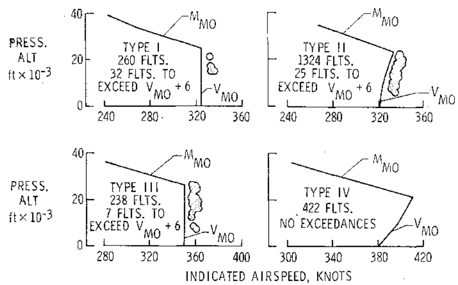

Fig. 13 Overspeeds.

amplitude oscillatory motion of one airplane type, no unusual events have been noted on the records from the two- and three-engine transports. Although the data sample is still too limited to be conclusive, it appears that some of the problems encountered with the four-engine transports have been avoided in the introduction of the two- and three-engine transports.

Concluding Remarks

Analyses of initial *VGH* data samples obtained from four types of two- and three-engine jet transports during operations on six airlines have provided preliminary information on the operational experiences of this recent class of transports. The results indicate that, in general, the gust acceleration, maneuver acceleration, landing impact acceleration, and gust-velocity experiences are not significantly different from those for past operations of four-engine transports. The differences which do exist are, for the most part, accountable for in terms of the airplane characteristics and flight profiles associated with the two classes of airplanes.

The average operating airspeeds for the two- and three-engine transports are similar to those for the four-engine transports. The present airplanes show less frequent and smaller margins of overspeeding than was evident during the initial operations of the four-engine transports.

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