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Study of CL-415 Usage in Forest Service Operation

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Results of analyzing airframe usage from a fleet of four CL-415 Super Scooper aircraft flown in support of the United States Forest Service aerial firefighting operations are reported. Data used for this report was collected over the calendar years 2015-2019 and consisted of approximately 4,700 hours of flight time. Firefighting missions have been divided into ten flight phases. Airframe usage has been examined for each flight and each phase of the flight. The results have been compared with aircraft limitations on airspeeds, altitudes, and load factors. Some incidents of excessive vertical acceleration and indicated airspeeds, for the corresponding flap deflection, are shown to have occurred. The largest and most frequent vertical load factors are shown to be associated with drop phases. Lack of clear indicators, such as weight on wheels, for water landings have prevented clear identification of points of contact with, and departure from, water. This has led to inclusion of water impact loads in the related *V-n* diagrams, which have been shown to be of significance.

I. Introduction

UNITED States Forest Service (USFS) uses a variety of aircraft in their firefighting efforts. Central to these missions are the airtankers that play a significant role in aerial firefighting missions. These aircraft have a quick response time and are especially effective in rough terrain [1].

In response to Recommendation A-04-29 [2] from the National Transportation Safety Board (NTSB), the USFS began requiring all aircraft operating under contract to be equipped with Digital Flight Data Recorders (DFDRs). This program has been aimed at monitoring factors that affected the fatigue life of these aircraft [3]. The flight data recorded by these aircraft, that is proprietary to the operators, is stored in a central repository. Wichita State University (WSU) is given access to this data for determining the statistical usage of the airframes and comparison of the results with the aircraft limitations. This information is also used to develop operational flight loads spectra. The results can be used by the Original Equipment Manufacturers (OEMs) and the operators to refine the aircraft limitations or maintenance and inspections schedules. If needed, these results can also be used by the regulating agencies to refine the standards governing such operations.

At the start of this program, the large airtanker fleet consisted mostly of reconfigured military aircraft such as P2V and P-3A whose data was analyzed first [4]. This was followed by examination of the flight data from a fleet of Beechcraft King Air twin turboprops that were flown in a variety of support roles [5, 6]. Over time, the operators gradually replaced the legacy airtanker fleet with newer, faster, and more cost-effective aircraft. One of the newer additions to the fleet, although not in the "large" airtanker category, is the Bombardier CL-415 Super Scooper.

The focus of this current paper is the CL-415. Although this aircraft is not in the large airtanker category, it is of particular interest due to the fact that it was designed for firefighting missions. The aircraft has a water capacity of 1,621 gallons and can fill without landing by scooping water from a source near the fire.

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In the current article, results are given for the ground-air-ground (overall) usage, with comparisons made between firefighting, ferry, and maintenance flights. In addition, the firefighting flights were separated into phases and results are provided. The statistical formats used for presenting the results are consistent with those used in the earlier reports of the FAA's Operational Loads Monitoring (OLM) program.

II. Method of Analysis

A. Flight Data and Preprocessing

The flight data for this effort was recorded at a uniform rate of 32 Hz and covered the calendar years of 2015 through 2019. Four airframes were used in this process with the data almost equally divided among them. This data is summarized in Table 1. The times shown here include those of ground phases. The data format varied among the aircraft and sometimes depending on the season. Therefore, all data was preprocessed and put in a uniform format prior to analysis. In this stage, the channels with binary signals were made consistent and the flap deflections where converted from degrees to discrete detents. The flap detents are defined in Table 3. Unfortunately, the pitch and the roll angle recordings were not deemed correct and were not used in this analysis.

Table 1. Number of Files Used for Analysis

Aircraft	Useful Files	Total Time (hr)
1	530	1,324
2	465	1,102
3	464	1,191
4	414	1,096
Total	1,873	4,713

Table 2. Data Channels Available for the Analysis

Channel	Parameter
1	Line Number
2	Elapsed Time (seconds)
3	Latitude (degrees)
4	Longitude (degrees)
5	Track (degrees)
6	GPS Altitude (feet)
7	Pressure Altitude (feet)
8	GPS Ground Speed (knots)
9	Vertical Speed (fpm)
10-12	Longitudinal, Lateral, Vertical Accel. (g)
13, 15	Pitch and Roll (degrees)
14, 16-17	Pitch Rate, Roll Rate, Yaw Rate (deg/s)
18	Dynamic Pressure (psf)
19	Static Pressure (psf)
20	Outside Air Temperature (Fahrenheit)
21-23	Indicated, Equivalent, True Airspeed (knots)
24	Weight on Wheels (binary)
25	Flap Position (detent)
26	Bay Door (binary)
27	Fill Probe (binary)
28	Water Quantity (gallons)
29	Terrain Elevation (feet)$^+$

$^+$ Added using USGS National Elevation Database and the latitude and longitude recorded by the DFDR.

Table 3. Flap Deflections in Degrees and Detents

Flaps per Aircraft Handbook	Recorded Values (deg)	Detent
0	0 < Deflection ≤ 7	Retracted
10	7 < Deflection ≤ 13	1
15	13 < Deflection ≤ 19	2
25	19 < Deflection	3

As an amphibious aircraft, landings could be on land or on water. Flights were defined as takeoff to landing, be it on land or on water. Ground landings and takeoffs could be determined with certainty from the status of the squat switch. However, water landings and takeoffs had to be based on indicated airspeed and *changes* in altitude. It was important to distinguish a water landing from a fill in which the aircraft skimmed the surface without the hull settling in the water. A water landing marked the end of a flight, whereas skimming the surface for a fill was considered as part of a flight.

A water landing was assumed if the squat switch was in the "in-air" mode and the airspeed dropped below a predetermined level and was below that value ten seconds later. Water takeoff was assumed if the squat switch indicated "in-air" and the change in altitude was greater than 15 feet in 10 seconds. While this logic worked adequately, occasionally it led to false indications of water landing resulting in inclusion of landing impact loads in flight loads.

Total flight time was defined as the time between takeoff and landing based on the logic described above. Flight distances proved to be most reliable from time integration of the true airspeed.

Normal acceleration was defined positive as upward, along the positive z-axis as shown in Figure 1. These accelerations were filtered using a low-pass, eighth-order Butterworth filter with an 8-Hz cutoff frequency. This was to remove any signals affected by local or airframe vibrations.

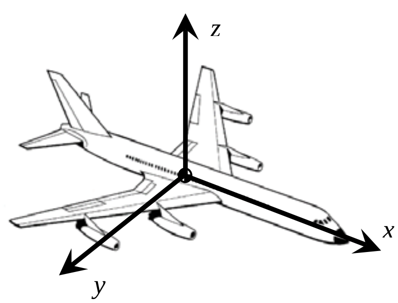

Fig. 1. Sign Convention for Accelerations

B. Phase Separation

The analysis was limited to that between takeoff and landing, whether on land or water. Ferry and maintenance flights were analyzed without consideration of flight phases. However, firefighting flights were separated into ten phases, as shown in Figure 2. The time history in that figure indicates a flight with one fill and one drop. The criteria for the separation is shown in Table 4. Because the phases could be short, there was no buffer left between the phases. Therefore, it is possible that some information from one phase could affect the results of the neighboring phases.

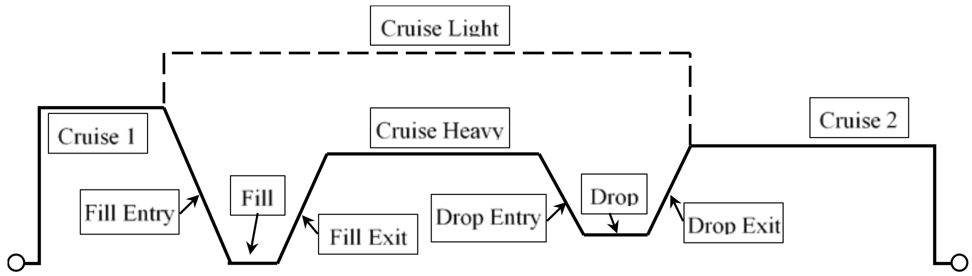

Fig. 2. Schematic of Flight Phases for Firefighting Missions

Table 4. Flight Phase Separation Criteria

Flight Phase	Start	End
Cruise 1	Start of flight plus 30 seconds	Start of first fill entry
Cruise 2	Start of flight plus 30 seconds for maintenance/training and ferry missions or end of last drop exit	End of flight minus 30 seconds
Fill Entry	One flap change before the start of the fill or 10 seconds	Start of fill
Fill	Initial water < 50 gal and change in water > 50 gal in one second and water level > 100 gal in three seconds and water level > 100 gal in five seconds and bay door is closed	Change in water < -10 gal over two consecutive half-seconds and water > 100 gal five seconds later and bay door is closed or fill probe retracting or 15 seconds after start
Fill Exit	End of fill	End of fill and one flap change or 10 seconds
Cruise Heavy (longer than 2 sec)	End of last fill exit	3 minutes or water drop more than 100 gallons 10 seconds ahead
Drop Entry	One flap change before the start of drop or 10 seconds	Start of drop
Drop	Opening of the bay door and water level changes more than 50 gals larger from 0.5 sec earlier to 1 sec later	Closing of the bay door and change in water level less than 5 gallons in two consecutive seconds
Drop Exit	End of drop	End of drop and one flap change or 10 seconds
Cruise Light (longer than 2 sec)	End of drop exit	3 minutes or water gain more than 100 gallons 10 seconds ahead

III. Results and Discussion

A. Ground-Air-Ground Usage

The results discussed here are based on airborne segments and consist of 2,032 flights and 3,981 hours, as shown in Table 5. Close to 80% of the data pertained to firefighting operations, while the rest were divided among ferry and maintenance/training missions.

The distribution of the number of flights by duration is shown in Figure 3. Firefighting flights had an average duration of 175.5 minutes. The ferry and maintenance flights had an average duration of 115.1 and 17.4 minutes, respectively. This is contrary to the heavy airtankers, in which the ferry flights have the longest durations and the firefighting flights have durations, on average, of less than 60 minutes.

Table 5. Total Duration for Each Mission

Mission Type	Number of Flights	Duration (hr)
Fire Ops	1,292	3,139
Ferry	442	762
Maintenance	298	80

The distance and duration are shown in Figure 4. The ferry flights are shown to have higher average flight speeds. The longest flights were slightly less than 6 hours. The maximum MSL and AGL altitudes and distance are shown in Figures 5 and 6, respectively. The highest MSL and AGL altitudes were associated with ferry flights. The MSL altitudes remained well below the aircraft's service ceiling of 20,000 feet. The majority of the flights had a maximum AGL altitude below 12,000 feet.

The flights based on the number of fills and drops is shown in Figure 7. The majority of the flights had 1-20 fills and drops. However, there was a noticeable number of flights with more than 20 fills and drops. It should be noted that some flights had multiple drops per fill. On average, there was 16,956 gallons of water delivered to the fire per flight. However, as shown in Figure 8, the amount of water delivered per flight reached 60,000 gallons in some cases. On the average, approximately 5,500 gallons of water was delivered per flight hour.

The frequency of flap deflections differed greatly between the missions, as shown in Table 6. The number of times the flap was lowered into each detent was shown to be higher for firefighting flights. The information shown in this table is only for in-flight deflections and does not include those that occurred before takeoff or after landing. The data indicated that the first two flap detents were preferred for fills and drops and the third detent was used mostly for landings.

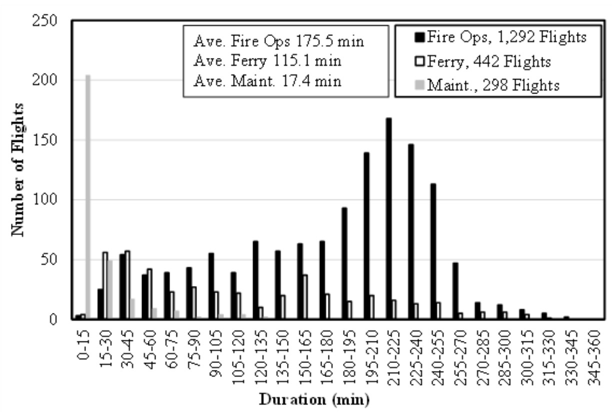

Fig. 3. Number of Flights Based on Flight Duration

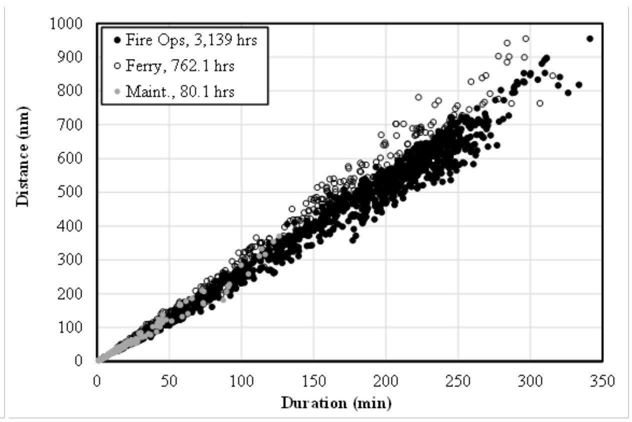

Fig. 4. Flight Distance and Duration

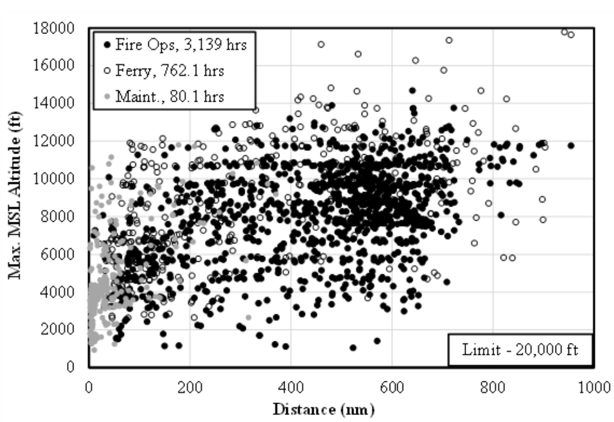

Fig. 5. Maximum MSL Altitude and Distance

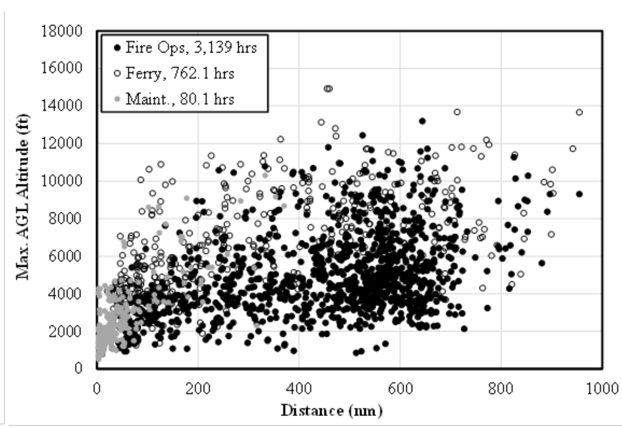

Fig. 6. Maximum AGL Altitude and Distance

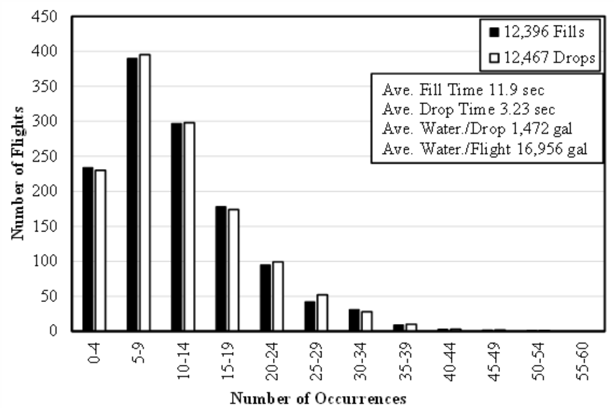

Fig. 7. Number of Flights and Fills and Drops

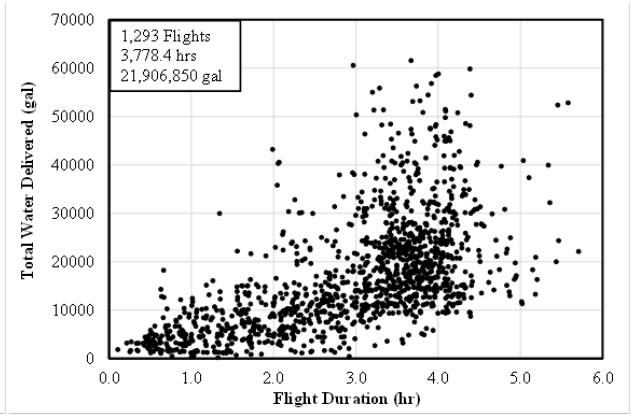

Fig. 8. Total Water Delivered and Flight Duration

Table 6. Frequency of Flap Deflections Per Mission

Missions	Detent 1	Detent 2	Detent 3
Firefighting	19.74	24.20	1.64
Ferry	1.40	1.14	1.02
Maintenance/Training	1.23	1.04	0.86

B. Flight Phase Usage

The firefighting flights were separated into ten phases and usage information was found for each. For the sake of brevity, only results for the fill and drop phases are shown here.

The average fill duration was approximately 12 seconds, as shown in Figure 9. Although the typical fill was shown to last anywhere from 7 to 15 seconds. It should be noted that, for this analysis, the fill phases were limited to 15 seconds and the phase duration would not exceed that. The maximum indicated airspeed during the fill phase was shown on average to be 79 knots, with the normal distribution shown in Figure 10. This is well below the limitation of 90 KIAS.

Shown in Figure 11 is the *V-n* diagram for the fill phase with the flaps in the second detent, which was the detent that was consistently used for the phase. During the fill, the airplane was subjected to large vertical load factors resulting from impact with the water. Therefore, the results shown in Figure 11 are not all flight loads, although it was impossible to separate those from the water impact loads. The maximum water speed of 90 KIAS is shown in Figure 11 and there are few cases in which the aircraft were flown faster.

The water volume after the fill phase is shown in Figure 12. The maximum tank volume was 1,723 gallons and the average volume during the fill exit was shown to be 1,561 gallons. Generally, the maximum water onboard occurred at the very start of the fill exit and occurred while excess water was still being shed from the aircraft.

The average drop duration was 3.25 seconds. However, a typical drop phase could be 2-4.5 seconds long, as shown in Figure 13. This was the shortest of all of the 10 phases analyzed. The average of the maximum indicated airspeed was 118 KIAS, as shown in Figure 14.

Typically, drops were initiated with the flaps in the second detent. However, the flaps were retracted quickly to the first detent at the end of the drop. Sometimes this flaps retraction occurred before the completion of the drop. Therefore, the *V-n* diagrams for detents 1 and 2 are shown in Figures 15-16 for the drop phase. Figure 15 shows that there were many exceedances of the airspeed and vertical load factor limits for detent 1. Most of these occurred at the end of the drop when the flaps were in transition between the two detents. Figure 16 shows that there were several airspeed exceedances for detent 2. In a handful of cases, the indicated airspeed was in excess of 10% above the limit.

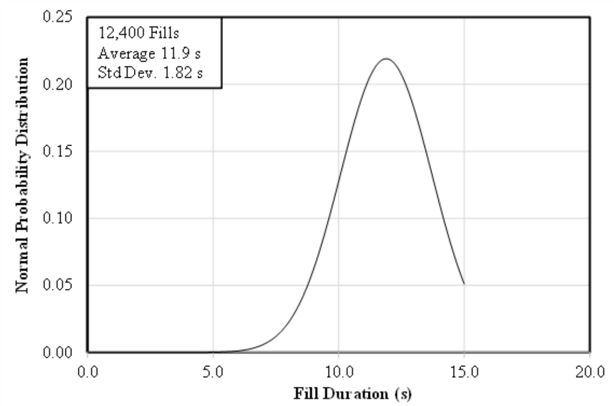

Fig. 9. Fill Duration

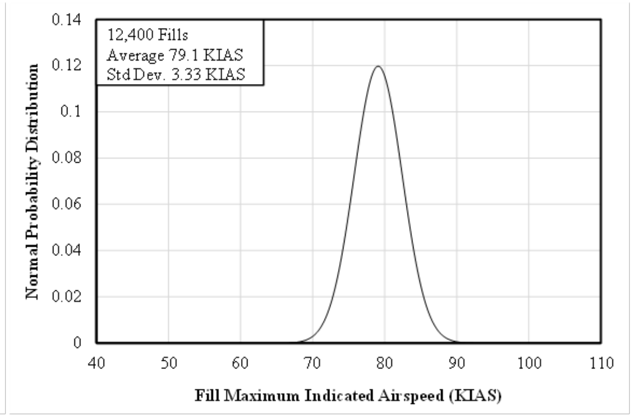

Fig. 10. Fill Maximum Indicated Airspeed

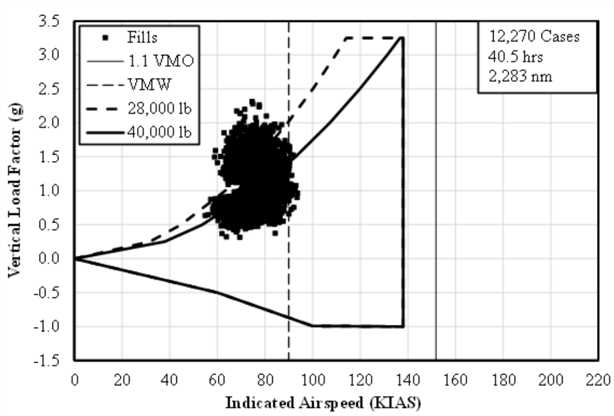

Fig. 11. *V-n* Diagram with Flaps in Detent 2, Fill

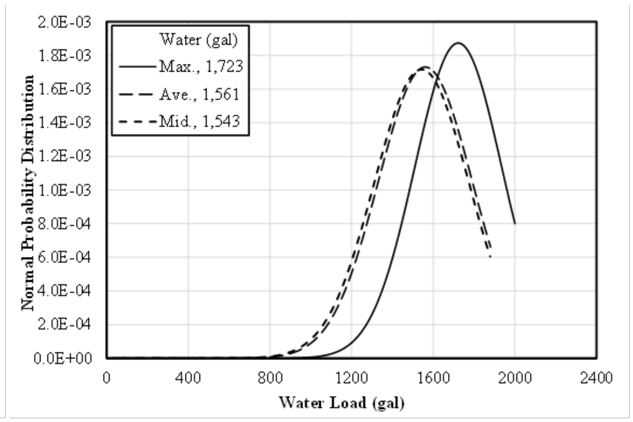

Fig. 12. Probability of Water Load, Fill Exit

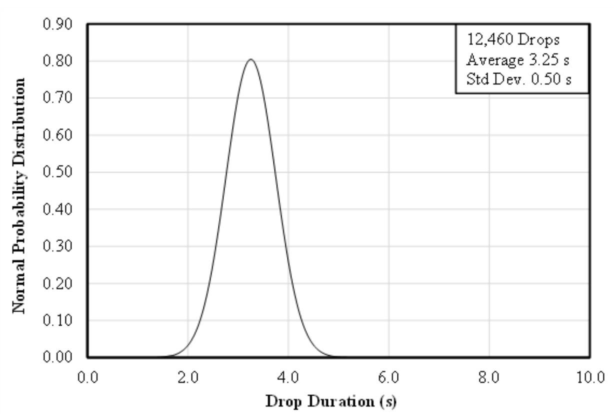

Fig. 13. Drop Duration

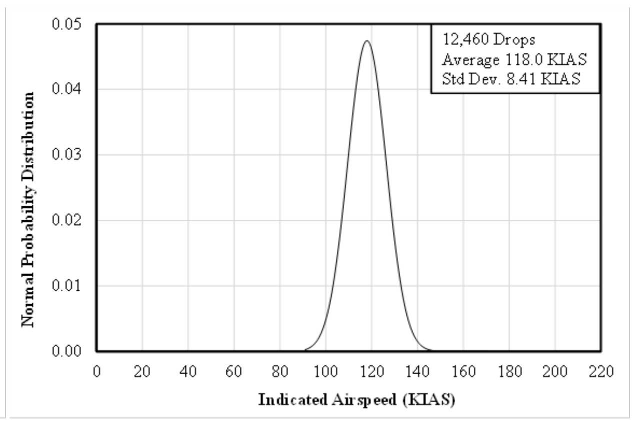

Fig. 14. Drop Maximum Indicated Airspeed

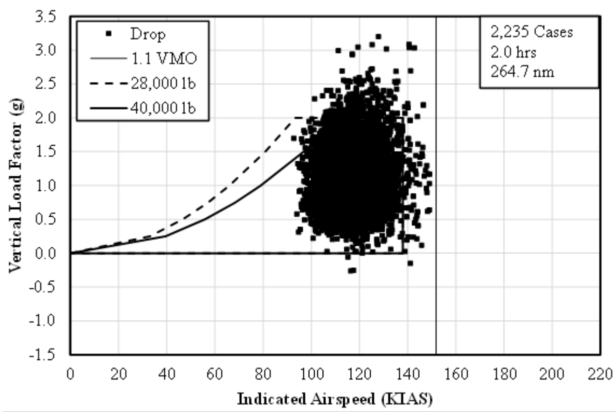

Fig. 15. *V-n* Diagram with Flaps in Detent 1, Drop

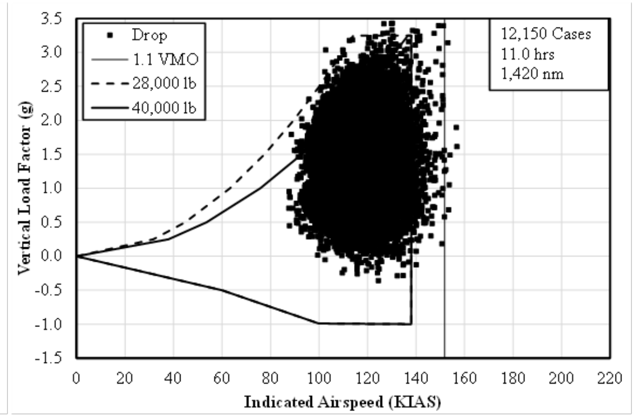

Fig. 16. *V-n* Diagram with Flaps in Detent 2, Drop

IV. Conclusions and Recommendations

Flight data were analyzed from four CL-415 airframes. Flights were separated into firefighting, ferry, and maintenance missions and usage information was presented. In addition, firefighting flights were further divided into ten individual phases. Usage results were presented for the fill and drop phases.

The longest flights were the firefighting missions in which the average duration was 175.5 minutes, almost four times as long as those of heavy airtankers. The longest firefighting mission lasted almost six hours. Firefighting missions with more than 20 fills and drops were not unusual. On average, 5,500 gallons of water was delivered per flight hour. Maximum altitudes seldom exceeded 14,500 feet with most of the flights remaining below 12,000 feet AGL or 14,000 feet MSL. No flight near the service ceiling of 20,000 feet was detected.

In the absence of any other indicator, water landings could be estimated only based on the airspeed. This led to the overlapping of the some of the flight phases surrounding fills and inclusion of water impact loads during these phases. Such water impact loads were shown to be significant.

The fill phase was defined as the segment where the tanks were being filled. This phase could be isolated very clearly. However, fill entry and fill exit phases could not be separated with clarity leading to inclusion of some water impact loads among their flight loads. Combining these phases into one focused on identification of water impact loads may be advisable.

Drop entry, drop, and drop exit phases could be identified with certainty. These phases subjected the aircraft to the most severe in-flight load factors. Drops were performed with the flaps in the second detent. However, in many instances, the flaps were retracted from the second detent into the first before the conclusion of the drop. Since the maximum allowable load factor for the first detent was lower than that of the second, this action led to exceeding the limit load factors. The drop rates were consistent with those observed on heavy airtankers.

Clear identification of the points of contact with, and departure from, the water source proved to be extremely challenging. If the aircraft are equipped with radio altimeter, direct recording of the AGL altitude would facilitate this process greatly.

Some of the overload cases are exacerbated by the aircraft's unusual limit load factors for various flap settings. Appropriate inspection procedures should be established if the observed exceedances of maximum airspeed and maximum vertical load factor are indeed real.

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