ICAS-86-4.5.2

A STUDY OF THE STRUCTURAL INTEGRITY OF THE CANADAIR CHALLENGER AT DITCHING

PETER T. TO
CANADAIR LTD.
MONTREAL, CANADA

ABSTRACT

The ditching characteristics and the structural response of the Canadair CL-600 Challenger was studied with a 1/10 scale instrumented dynamic model. The peak structural loading occurs when the attitude of the aircraft reduces abruptly after attaining a high pitch up angle which has been gradually building up from the initial impact. To optimize the acceleration and impact pressure emergency landing on water should be carried out at speed slightly higher than the stall speed with flaps extended and landing gears retracted. In high sea states, a parallel landing on the crest of the waves will improve the chance of successful ditching though the impact pressure is compromised. The relatively mild and brief acceleration and favourable post ditching flotation will provide satisfactory occupant survivability.

I. INTRODUCTION

Due to the possible requirement of emergency landing on water, such as fuel exhaustion[1], or propulsion difficulties[2], satisfactory ditching characteristics, including the hydrodynamics, structural strength and flotation, are essential to enhance the survivability of the occupants. The ditching characteristics of the Canadair Challenger CL-600 was studied with free launching scale dynamic model.

To maintain the Froude Number same as the full scale during the test, the test parameters and result interpretation are in compliance with the following relationships where n is the linear scale reduction of the model:

Weight	$1:n^3$
Velocity	$1:\sqrt{n}$
Acceleration	$1:1$
Pressure	$1:n$
Time	$1:\sqrt{n}$
Force	$1:n^3$

It is then apparent that the Reynold Number can not be duplicated during the test. The reduced lift and premature stalling on the model due to the lower Reynold Number can be improved by increasing the wing chord, installing leading edge slats, incorporating geometric wash out and increasing the camber etc. However, due to the hydrodynamic side effects associated with these devices, it was decided to minimize the effect of premature stalling by launching the model close to the water suface. Due to the same effect, the tail plane of the model will be less effective than that of the prototype, trimming to the required test condition is determined from wind tunnel testing of the model prior to the simulated ditching tests. Similarly, the "slamming" or impact pressure measured during test will be higher than the full scale environment due to the difference in Mach Number.

II. MODEL DESIGN CRITERIA

The 1/10 scale was chosen for practical design reasons, including the fabrication and strength of the model, amount of sensors and telemetric devices on board and launcher capacity.

As it is impractical to construct a complete scale-strength model, understanding the effects of aircraft configuration on ditching behaviour is therefore essential to the design of a representative engineering model for the study.

Landing Gear

With apparently no exception, experimental data ranging from large transport aircraft[3] to space shuttle[4] indicates that extended undercarriages is a disadvantage to ditching. Though the undercarriages may reduce the aircraft forward speed prior to the fuselage contact with water, thus reducing the acceleration and impact force, the high risk of causing extensive damage to the fuselage shell and inducing nose down pitching nullifies the potential advantage associated with the extended undercarriages. Simulation of the landing gears is therefore not incorporated.

Flap Setting

Forward speed is probably one of the most important parameters affecting the ditching quality, as the deceleration, stability and impact pressure are usually improved at reduced speed providing that the aircraft does not stall prior to impact. A significant reduction on the stalling speed can be conveniently achieved by extending the flaps. The need to determine the use of flaps for ditching is apparent as they may induce highly undesirable nose down pitching and subsequent diving if the hydrodynamic force acting on the flaps continues for an extended period of time. This is particularly important to a low wing aircraft as the trailing edge of the flaps is the first point of contact with water in some ditching conditions. It is impractical to duplicate the structural arrangement in review of the difficulties of repairing and retreiving the components frequently. To provide an effective simulation, hinged brackets, which are not different in principle from the full scale aircraft, were used in conjunction with shear pins which were calibrated to the strength of the flaps as shown in Figure 1. The flap is forced to retract to the 0° flap position if the impact force on the flap is sufficient to overcome the strength of the flap joints. Provision was made for runs with 45°, 20° and 0° flap settings.

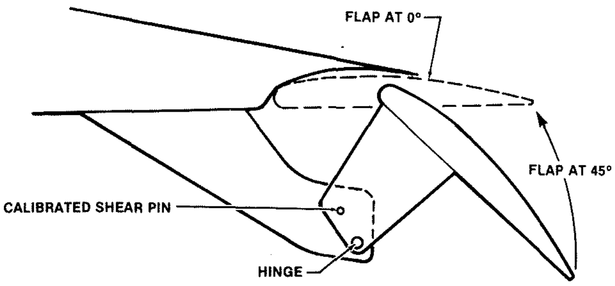

Figure 1. Scale-strength Flap Joint

Tail Plane

The tail plane, acting together with the wings, often serves as a hydrodynamic surface in the planing stage and limits the suck down phenomeneon of the aft body. If abrupt structural failure of the tail plane occurs during this ditching segment, hazardous instability may be produced. Since the Challenger has a high T tail, the scale-strength simulation is therefore not required, and was later confirmed by trial runs. For the purpose of aerodynamic trimming during the free flight segment, the tail plane was made adjustable to trim according to wind tunnel test data.

Wing/Fuselage Fairings and Access Doors

The Kevlar wing to fuselage fairings are designed to withstand service aerodynamic loads which are expected to be exceeded by the force arising from impact with water. The effect of stepped surfaces, as a result of damaged or separated aerodynamic fairings, was investigated by removing the detachable parts for some of the runs. Similarly collapsed access door was represented by its removal. Combinations of fairing configurations used for the investigation are tabulated in Table 3.

Fuselage Structural Strength

Structural integrity of the cabin is vital to the survivability of occupants at ditching. Other than the requirement of determining the transient impact pressure which can be as high as 200 psi for a short duration[5], it is imperative to demonstrate that the fuselage is capable to sustain the inertia loads during various phases of the water landing without catastrophic structural failure. The local transient pressures were measured by pressure transducers installed at the lower fuselage of the model, while the strength of the fuselage was represented by scale-strength fittings as shown in Figure 2 and Figure 3. Each of the scale-strength fittings consists of a narrow notched aluminum strip which is calibrated to the equivalent fuselage strength of the full scale aircraft. The sharp notches were incorporated to ensure fracture at the predetermined load and to facilitate verification. To prevent extensive model damage in case of overloading, tail-safe strap with oversized holes was loosely fastened to the scale-strength fittings to prevent total fuselage separation. Accelerometers were mounted at strategic locations to measure the longitudinal and vertical accelerations for calculating inertia loads and evaluating the survivability of occupants.

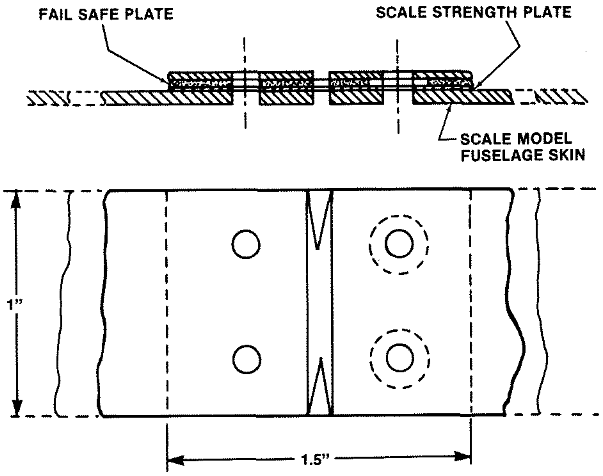

Figure 2. Fuselage Scale-strength Fitting

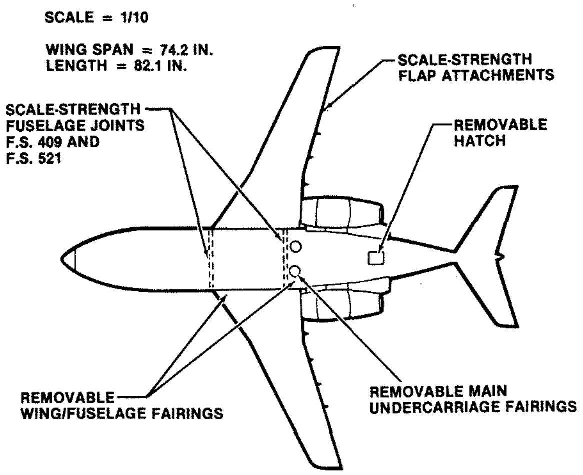

Figure 3. Scale-strength Components of Model

III. DITCHING TEST CONDITIONS

The most important factors to be considered prior to ditching an aircraft are:

(a) forward speed
(b) sink speed
(c) aircraft attitude
(d) approach technique with respect to the direction of waves

The first three factors, together with aircraft weight, flap setting and glide slope, are inter-related by the relationship determining the lift and cannot be varied without affecting one or more of the other parameters. However, the general effect of each of the factors should be understood in order to reduce the number of runs to an acceptable limit.

Forward Speed

With other flight parameters kept constant if physically possible, it is generally best to alight at as slow a speed as possible. This is because the impact forces and pressure at the initial impact are expected to be approximately proportional to

$$V^2 \sin^2(\phi_f + \epsilon) \cot \beta \qquad (1)$$

where

V = Velocity along flight path

ϕ_f = angle of the fuselage attitude to the water surface

ϵ = angle of descent

β = angle between the local surface of the fuselage and the water.

In addition, longitudinal instability can be much more dangerous if it develops at high speed. However, a low speed must not be obtained at the expense of increasing the angle of descent or stalling prior to touchdown. Test runs were carried out at 1.1, 1.2 and 1.3 times the stall speeds.

Stall speed can be reduced effectively by use of flaps providing that the side effects are acceptable as discussed earlier. Since the stall speed varies approximately to the square root of the weight, two aircraft weights, i.e. 27500 lb. and 36000 lb., were investigated during the test program.

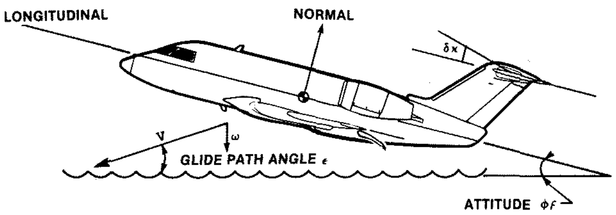

Figure 4. Ditching Attitude

Sink Speed

It is obvious that the ideal alighting may be achieved by reducing the sink speed or angle of descent to near zero at touchdown by using engine power or other means. However, it is most difficult, and sometimes impossible to judge the height for flattening out at night or at some sea states. As it is more predictable to ditch the aircraft in such cases with the "fly on" technique which calls for a slow shallow powered glide, tests were carried out with sink speeds of 3 f.p.s. and 5 f.p.s.

Aircraft Attitude

To generalize the optimum attitude for the aircraft to have at touch down is by no means a simple task. Theoretically, the impact pressure is approximately proportional to the square of the flight velocity and attitude. Reducing the attitude will cause an increase in flight speed which is required to maintain the same lift. On the other hand, increasing the attitude will probably lead to a higher angular velocity at impact partly due to the aft shift of the impact point along the longitudinally curved rear fuselage.

Of more importance than the initial impact pressure is the subsequent behaviour of the aircraft. If the conditions are unfavourable, the initial impact moment may cause sudden change in trim which, in turn, may lead to nose diving or porpoising. Compatible with other flight parameters, test runs were performed with attitude ranging from about 1° to 12°.

Wave or Sea State

The behavior of the aircraft at ditching is very much complicated by the presence of waves. The direct effect of the wave is modifying the relative vertical velocity between the aircraft and water surface. The change of velocity may be estimated by the following expression[6]:

$$h\sqrt{\frac{\pi g}{2L}} \qquad (2)$$

where

h = wave height

L = wave length

g = gravitational acceleration

A sea state of 4.3 feet high and 120 feet long that is commonly referred as "rough sea" causes an increase of 3 f.p.s. in the relative vertical speed. Such an increase is certainly significant compared with the 3 to 5 f.p.s. nominal sink speed of the aircraft.

The wave also changes the loading geometry both locally and aircraft-wise. As approximated by Equation (1). The impact pressure is modified by the relative angle between the local fuselage contour and the wave surface. At the same time, the impact point along the longitudinal axis is changed from a predetermined region, which is defined by the attitude of the aircraft when ditching in calm water, to almost any location along the fuselage if the aircraft alights across the waves. Due to the high risk associated with the head on impact with an oncoming wave, tests were carried out with flight path parallel to waves only.

Some aircraft may experience lower impact pressure by landing on the falling slope of the wave, but for the CL-600 which has a low wing of 61.8 ft span, landing parallel on the crest may be more preferrable to avoid the risk of possible cartwheeling when one of the wing tips catches water first. Trials were carried out to determine the behavior of various landing techniques on waves. Wave conditions similar to Sea state 3 and 4 were simulated.

IV. TEST RESULTS

Other than several unsatisfactory runs due to experimental difficulties or loss of telemetric data, a total of 52 successful launches were carried out during the program.

General Behaviour

The general sequence of model ditching in calm water usually commenced with the rear fuselage making contact with water, followed by a smooth reduction in attitude until the lower wing skin formed a planing surface, Figure 5.

Due to the negative hydrodynamic pressure acting on the aft fuselage body, the aircraft attitude was trimmed gradually to about 25°, and sometimes as high as 40°. It was then followed by a pitch down motion, or slamming in some cases. The near level forward motion was then reduced to a moderate speed of about 30 knots while retarding to a halt. For some shallow angle landings at high speed, porpoising or ricochetting occurred instead of the trim and pitch down routine. Due to the "clean" underbody profile, the nominal distance traveled from the point of initial water contact to stop was about twenty aircraft lengths.

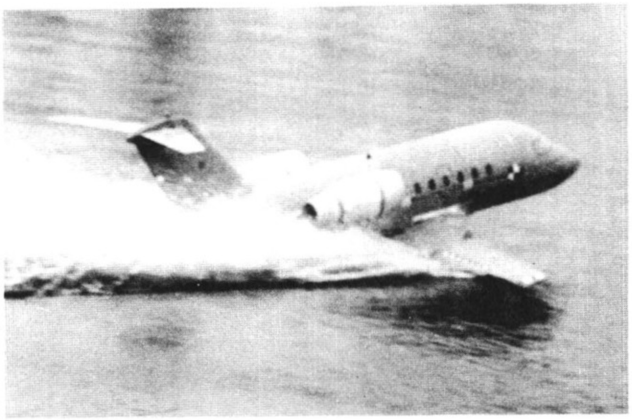

Figure 5. Initial Impact

Strength and Effects of Flaps

The use of flaps at ditching was found to be benefitial from the model ditching test as it reduces the landing speed which generally affects the acceleration and impact pressure. The calibrated shear pins were fractured at the instant of initial water contact causing flap retraction, this represents a flap joint failure and separation in the full scale environment. Flap separation is essential to eliminate the high nose pitch-down moment which may subsequently cause hazardous nose diving. Full flap, i.e. 45°, is recommended to maximize the speed reduction. However, during several 20° flap ditchings in wave conditions, the model exhibited lateral instability and followed by nose diving, such configuration should therefore be avoided.

Accelerations

The vertical acceleration usually peaked shortly after the fuselage had made the initial contact. For those runs that attained a relatively steep attitude when the aft body was sucked in due to planing pressure, the acceleration associated with the slamming sometimes exceeded that of the initial impact, Figure 10. Among the recorded data, Table 5, the highest vertical acceleration consistently occurred in the cockpit as the acceleration was partly induced by the aircraft rotation pivoting about the rear fuselage. Typical response of the accelerometers for calm and rough water conditions are as shown in Figure 9 and Figure 10 respectively. The average maximum vertical acceleration is about 10 g's.

Due to the smooth underbody contour, the longitudinal accelertion is relatively low, about 3 g's in calm water conditions. The longitudinal acceleration always peaked at the moment when the aircraft was at a near level attitude after the initial impact. Test data shows that there is negligible correlation between longitudinal acceleration and flight parameters.

As a result of the large number of variables which could not be kept constant during the test program because of physical limitations, a precise parametric study of the variables could not be performed. Nevertheless, despite the effects from other parameters and experimental scatter, the trend of increasing acceleration with higher speed is still apparent in Figure 8. Of equal importance, some of the high speed runs exhibited porpoising and skipping which may lead to lateral instability sometimes. Such instability may be critical in more severe weather conditions.

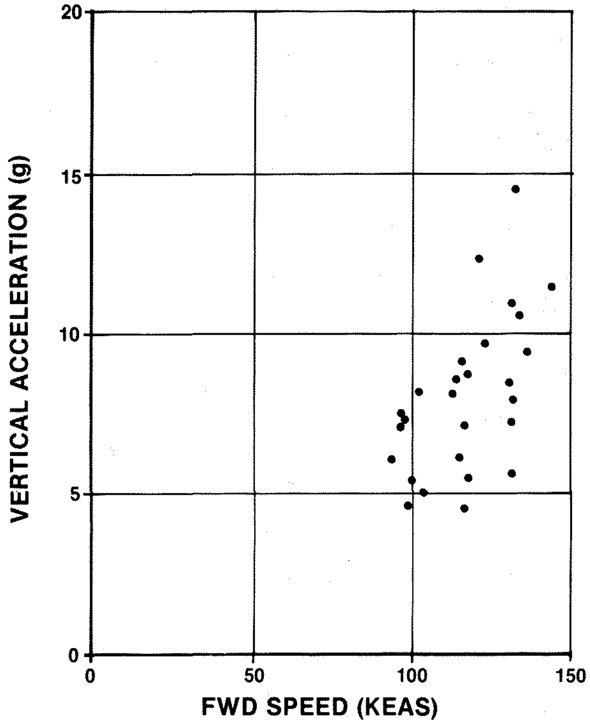

Figure 8. Correlation of Acceleration and Speed

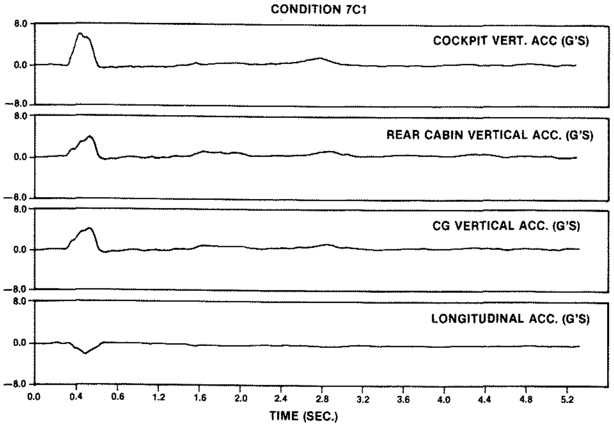

Figure 9. Measured Acceleration in Calm Water

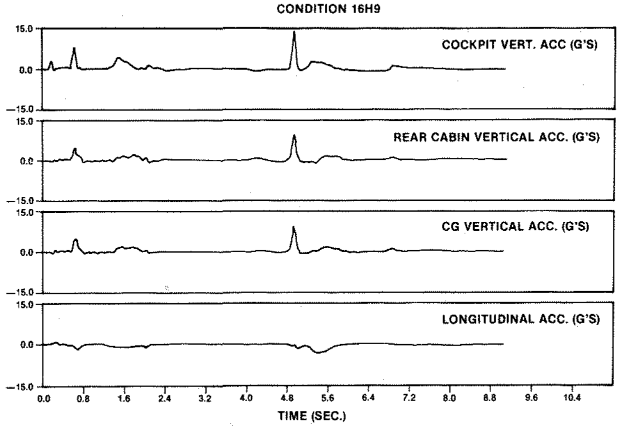

Figure 10 – Measured Acceleration in Rough Water

Local Pressure

Data recorded as shown in Figure 11 are local pressures at points located at the bottom of the fuselage. The first major pressure response is caused by the initial impact. Note that there is an approximately 0.4 second delay from the initial impact. The peak pressure reaches about 130 psi which is typical for most conditions carried out. Since the peak pressure drops off rapidly away from the impact point both in the longitudinal and circumferential directions Figure 14, the average impact pressure is not prohibitive. Furthermore it should be noted that the peak pressure lasts for a very short duration, typically 20 msec, then reduces to 30 psi and 70 psi for locations 3 and 4 respectively. Skin panel, similar to that of the CL600 fuselage configuration, has been demonstrated experimentally to be capable of sustaining dynamic load of similar magnitude and duration without catastrophic failure.

The second major pressure response, approximately 4 sec after the initial impact, is associated with the slamming following the trim-up manoeuvre. Again, the magnitude is generally much lower in the forward fuselage.

Fuselage Loads and Strength

The eight calibrated scale-strength fuselage joints were found undamaged after all of the runs, indicating that the fuselage is expected to remain intact in the full scale environment. The inertia loads, calculated based on the measured accelerations, are compared with the strength of the aircraft. Both the vertical bending moment (Figure 12) and vertical shear (Figure 13) are shown to be within the design envelopes of the fuselage with significant margins. This further confirms the validity of the scale strength simulations.

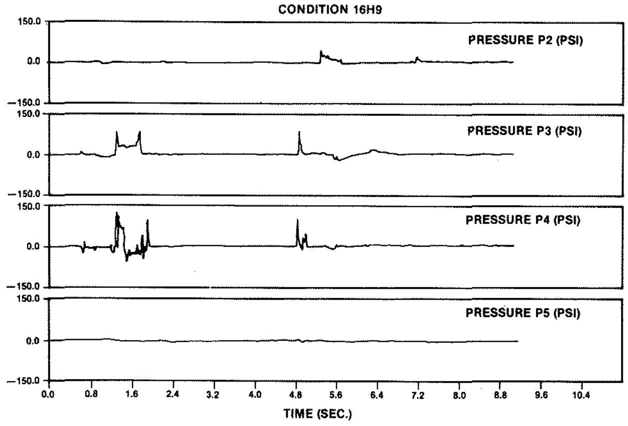

Figure 11. Measured Acceleration in Rough Water

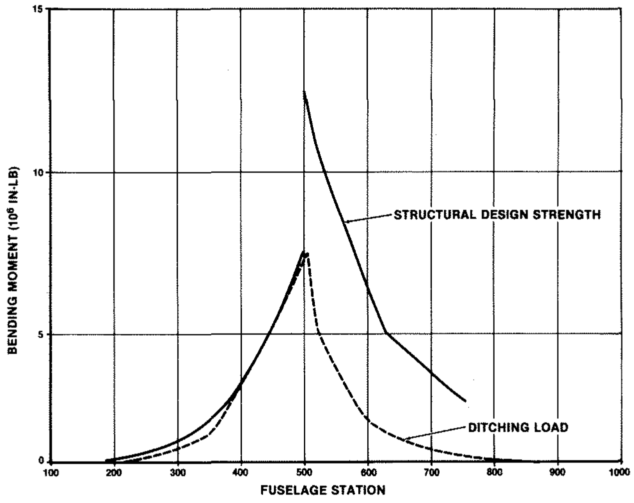

Figure 12. Fuselage Bending Moment Comparison

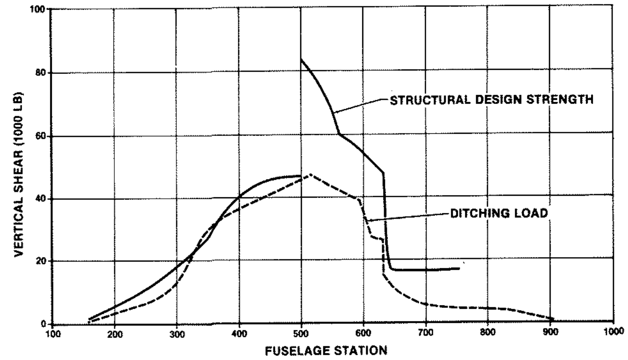

Figure 13. Fuselage Vertical Shear Comparison

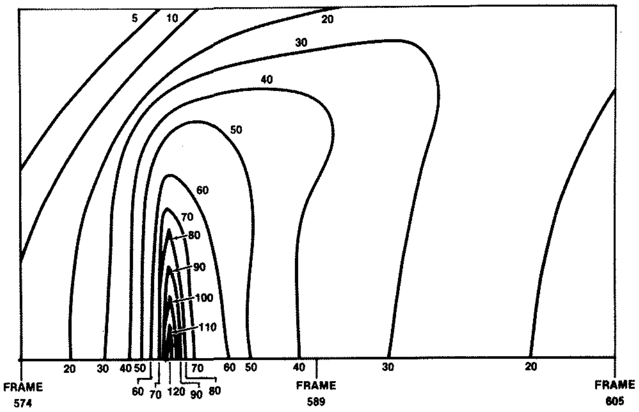

Figure 14. Impact Pressure Distribution (p.s.i.)

Since the fuselage to wing fairings were not expected to remain intact, damage simulation by exposing the contours of the interior structure showed neither significant effect on the behavior nor increase in accelerations.

Though the tests have demonstrated satisfactory structural strength, some form of local leakage is likely to occur if the ditching is executed in a more hostile environment. Flotation of the model aircraft was found to be satisfactory even with access door damage simulated, Figure 17. Both the passenger door and overwing emergency exit were above water, but egress through the rear baggage door should be avoided to prevent flooding the cabin.

Landing on Waves

A large percentage of runs were dedicated to determine an optimum technique to land in simulated rough sea. Parallel landing on the crest of the waves was found to provide satisfactory overall behavior consistently, Figure 15. By adopting such approach there was no obvious difference in accelerations and impact pressure compared with the calm water runs, other than the usual large data scatter which appears to be common in these type of tests.

Some aircraft may be required to land on the falling slope or the trough of the waves in order to reduce the impact pressure, but it was found that undesirable cartwheeling occurred sometimes when one of the wing tip caught the wave while attempting to land on the falling slope, Figure 15. A typical satisfactory ditching run in simulated rough sea is illustrated in Figure 16.

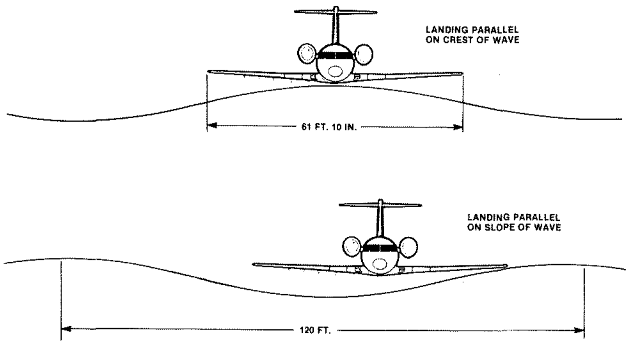

Figure 15. Landing Approach on Waves

V. CONCLUSION

The result of ditching tests of a dynamic scale model of the Canadair Challenger business transport aircraft indicates that the most favorable condition for emergency landing on water is 8° landing attitude, 45° flaps and as slow landing speed as is consistent with adequate aerodynamic control prior impact. The aircraft structure, as indicated by scale-strength joints and transducers, is not expected to have catastrophic failure though local fuselage damage is possible in more hostile ditching environment. Parallel ditching on the crest of waves is recommended as test runs produced stable characteristics consistently. The overall occupant survivability is expected to be satisfactory due to the relatively survivable accelerations and favourable post ditching flotation.

VI. ACKNOWLEDGEMENTS

The author of this paper is indebted to the Canadair Management for creating the opportunity to make such studies and presentation. Appreciation is also extended to the NRC, Ottawa for carrying out the tests and providing the photographs. Finally, the author is grateful to Messrs D.R. Turner, R. Banister and F. Mavriplis, whose advice and guidance have been invaluable.

VII. REFERENCES

1. National Transportation Safety Board, Aircraft Accident Report NTSB-SA-420

2. National Transportation Safety Board, Aircraft Accident Report NTSB-AAR-79-13

3. William C. Thompson, "Ditching Investigation of A 1/30-Scale Dynamic Model of A Heavy Jet Transport Airplane", NASA TM X-2445

4. W.L. Thomas, "Ditching Investigation of a 1/20-Scale Model of the Space Shuttle Orbiter", NASA CR-2593

5. A.G. Smith, C.H.E. Warren and D.F. Wright, "Investigation of the Behavior of Aircraft When Making A Forced Landing On Water", R.A.E. Report No. AERO-2457.

6. A.G. Smith, D.C. Appleyard, R.J. Monaghan and R.A. Weatherlead, "Some hydrodynamic and structural Aspects of Design for the Ditching of Landplanes "R.A.E. TN No. AERO-1848.

Figure 16a. Model Prior Ditching in Rough Water

Figure 16d. Model Pitching Down

Figure 16b. Parallel Landing on Crest of Wave

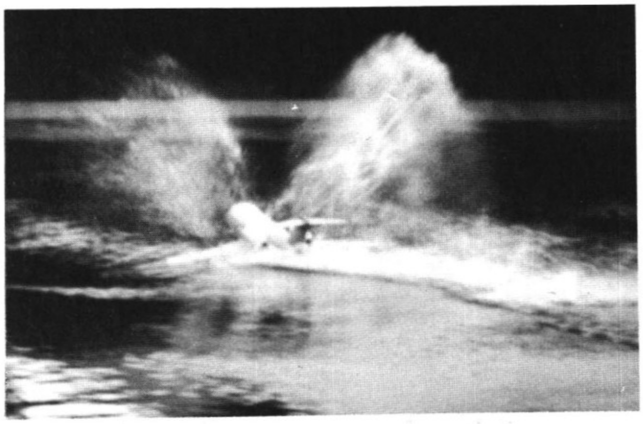

Figure 16e. A Harder Than Average Slamming

Figure 16c. Rear Fuselage Being Sucked Down

Figure 17. Post Ditching Flotation

Flight Condition No.	Descent Rate (ft/sec)	V/Vs	Flap Angle δ_F (deg)	Flight Path Angle ε (deg)	Aircraft Attitude ϕ_F (deg)	Aircraft Forward Speed KEAS
1	2.5	1.10	45	-0.89	8.81	95.5
2	2.5	1.10	20	-0.82	10.58	103.9
3	2.5	1.10	0	-0.74	11.86	114.6
4	2.5	1.20	45	-0.81	5.29	104.2
5	2.5	1.20	20	-0.75	7.85	113.4
6	2.5	1.20	0	-0.68	9.52	125.0
7	5.0	1.10	45	-1.78	7.92	95.5
8	5.0	1.10	20	-1.63	9.77	103.9
9	5.0	1.10	0	-1.48	11.12	114.6
10	5.0	1.20	45	-1.63	4.47	104.2
11	5.0	1.20	20	-1.49	7.11	113.4
12	5.0	1.20	0	-1.36	8.84	125.0
13	5.0	1.30	45	-1.44	0.96	118.2
14	5.0	1.10	45	-1.50	6.75	112.9
15	5.0	1.20	45	-1.38	3.57	123.2
16	5.0	1.30	45	-1.27	1.13	133.5
17	5.0	1.10	20	-1.41	9.69	120.1
18	5.0	1.20	20	-1.30	6.95	131.0
19	5.0	1.10	0	-1.28	11.07	132.4
20	5.0	1.20	0	-1.18	8.77	144.4
21	5.0	1.20	20	-1.23	5.40	138.5

TABLE 1 - FLIGHT CONDITIONS

Water Condition Code	Description
C	Calm Water
W	Wave 2.5 ft high. 120 ft long
H	Wave 4.3 ft high. 120 ft long

TABLE 2 - WAVE CONDITIONS

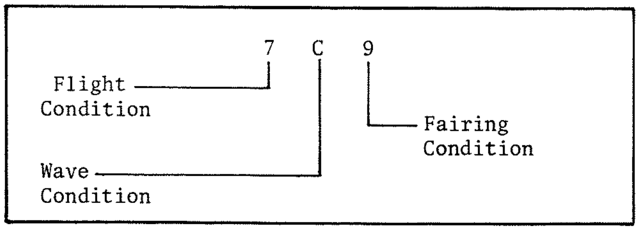

TABLE 3 - TEST CONDITION CODE

Fairing Condition Code	Description
1	All removable fairings and hatch on
2	Forward wing/fuselage fairing removed
3	Aft wing/fuselage and undercarriage fairings removed
6	Conditins 2 and 3
7	Aft fuselage hatch removed
8	Conditions 7 and 3
9	Conditions 7 and 6

TABLE 4 - FAIRING CONDITIONS

Cond.	Max. Accel (g)				Max.Pressure (psi)			
	A1	A2	A3	A4	P2	P3	P4	P5
2C1	8.2	5.7	5.5	2.5	3	38	53	-
8C1	5.0	3.1	3.2	1.6	22	20	76	-
8C1	5.4	2.8	3.1	1.4	13	29	46	4
7C1	7.5	3.8	3.8	1.6	5	36	2	5
7C3	7.1	3.7	4.2	1.9	0	91	0	0
7C6	5.9	2.3	5.0	4.6	83	1	1	0
7C3	7.4	4.7	5.3	1.4	-	-	-	-
7W3	7.1	2.6	4.7	5.5	-	-	-	-
7W3	4.3	2.4	2.3	1.4	71	47	9	2
7W3	6.0	3.5	3.9	2.1	75	77	49	46
7W3	6.5	2.3	3.0	5.8	70	56	43	8
7H9	6.5	3.3	4.3	5.8	38	51	2	5
10H9	6.3	3.5	3.5	8.0	43	7	1	49
7H6	6.3	3.8	4.4	3.8	23	5	3	4
7C1	8.7	5.4	6.5	6.2	80	1	2	2
7H3	4.3	2.4	2.5	2.5	84	93	40	4
7H6	6.6	2.6	3.2	6.7	55	57	28	4
7H6	4.1	2.8	3.1	1.8	-	-	-	-
7C1	6.07	3.95	4.18	2.23	3	72	124	126
5C1	5.48	2.41	2.76	1.42	2	62	128	103
11C1	4.53	1.46	2.25	3.77	4	94	118	12
11C1	5.57	3.78	4.09	1.53	3	139	132	145
3C1	8.68	4.73	6.57	1.19	42	107	117	129
9C1	9.33	6.05	6.83	1.73	29	50	129	143
12C1	9.75	6.34	6.09	1.29	44	103	126	137
8H9	4.81	3.89	5.32	5.03	74	33	4	3
11H9	5.72	4.40	4.31	4.32	24	8	12	0
8H9	8.37	5.23	6.84	1.45	26	95	33	23
9H9	5.20	2.78	3.24	2.67	15	138	101	26
11H9	6.99	3.86	4.25	2.24	61	128	94	4
12H9	9.70	4.19	4.80	1.47	3	3	127	5
12H9	8.14	3.90	4.67	3.28	16	1	128	50
13C1	8.71	4.72	5.18	2.89	77	55	128	92
13H1	5.41	2.98	2.95	6.18	42	77	105	36
13H1	7.73	3.87	4.39	3.92	38	83	129	125

TABLE 5 - MEASURED ACCELERATION AND PRESSURE OF 27,500 LB RUNS

Cond.	Max. Accel (g)				Max.Pressure (psi)			
	A1	A2	A3	A4	P2	P3	P4	P5
14C1	8.11	4.55	5.05	.93	0	92	126	144
16C1	10.60	6.42	6.60	2.37	32	80	125	149
18C1	10.49	3.34	5.50	4.81	30	96	125	151
18C1	5.59	2.58	2.64	5.49	6	74	125	152
18C1	7.35	2.66	3.52	6.27	11	15	129	127
18C1	8.04	3.48	4.14	5.63	34	5	2	147
18C1	8.51	4.92	5.57	2.68	10	85	109	82
16H9	13.66	8.97	9.42	3.36	41	86	129	1
17H9	9.82	4.41	5.05	2.65	45	84	111	6
18C1	8.39	3.17	3.50	5.16	40	29	18	147
21C1	9.48	7.45	5.59	1.85	0	54	125	146
20C1	11.51	6.45	5.85	2.00	4	69	134	82
19C1	14.59	7.89	8.20	2.68	71	40	144	144
17C1	12.31	7.08	7.47	1.55	77	73	143	160
20H9	7.71	9.58	4.23	7.31	66	64	99	3
20H9	10.05	3.98	5.14	3.60	0	62	157	3
21H9	10.07	-	5.54	4.40	-	-	-	-

TABLE 6 - MEASURED ACCELERATION AND PRESSURE OF 36,000 LB RUNS