TL. 112-00/00

Outline for CF-100 flight testing

Instrumentation
- Photo-recorder
- Oscillograph
- Telemetry Station & magnetic tape

Taxi runs oscillating nose wheel aft door.

Bill Waterton
- Reception
- Early flights
- Demonstrations
- His interpretation of speed & embarrassment to AVRO
- Failure to follow test plans
- Joy in Gloucester
- Wright Field tests, no security clearance for Waterton.
  - Bob Christie RCAF stationed at Wright Patterson.

Wing replacement rejected dive brakes
Paul Hartman & Shan Badeau famous Sunday
Long range tanks and instability -add fins
The bumps and snapping wings-Bruce Warren's input
Session at Wright Field- General Davis, Bob Christie
    Leading edge/nacelle shift; used tape as a seal
Bob Ostrander/ Bruce Warren fatality
Safety and flight pay
Enter Jan Zurakowski & Peter Cope
Jato take-offs at Ottawa
Fuselage fairings-got nowhere
John Heibert-18112 Rocket Pack
Gun Firing- Gas Detection -Peter Cope bullet in cowling
Mach 1.07
Vortex Generators, drooped flaps and aileron
Thin Wing
Mark 4 Fairing at leading edge/nacelle (data from Northrup\Whittely)
Mark 5- Crash at Malton Airport Perimeter
Commander Fifield ejection & Mr. Martin (Martin/Baker)
Canopy ejection at Camp Borden
Rocket Pod firing and ejection
Anti-icing trials Don Rogers
Spin recovery parachute
Resetting tailplane incidence
Broken Spar and fix by Czerwinski
Cold Lake contingent
Observer's safety screen Don Ridler
Airspeed Calibration, Photo technique and USAF pacer
Trip to Minneapolis Honeywell on RCAF Beech, F/Lt Bob Christie

I HAVE A STORY ON MOST OF THESE ITEMS!

Yaw damper
Hunt for Chief Aerodynamist replace Chamberlin?
England Ellis (drinking problem)
Convair ? (didn't like what he saw)
Bob Lindley's development plan

The CF-100 initial flight took place in January, 1950, about five months after the Jetliner's first flight. This placed a heavy demand on our meager flight test facilities and personnel. As usual there was little time allocated to our flight test group to install instrumentation and recording devices. This delay was to have a devastating effect on the over all CF-100 program as many shortcomings in the aircraft design were not revealed early enough to take corrective action prior to the commitment of production tooling and the acquisition of materials which resulted not only in increased costs but an embarrassment to the company as a whole. Later C.D. Howe would publicly express his lack of confidence in our technical and managerial(?) ability.

Enter Squadron Leader W.A. "Bill" Waterton

Sir Roy Dobson selected Bill Waterton who was the chief test pilot at Gloster in England to conduct the early testing of the Cf-100 much in the way that Jimmy Orrel had so successfully performed on the Jetliner. Were we ever in for a rude shock!

Waterton arrived in the late fall of 1949 to prepare for the CF-100 flight trials which were expected to start before the end of the year. The first flight took place on----------------.
There was insufficient time, or rather no time allocated for the installation of the instrumentation due to the pressures to get the maiden flight over with. Bill Waterton had achieved the honour of holding the world's speed record on the Gloster Meteor aircraft shortly after the war, when he broke the 600 mile per hour barrier. I believe that this record of ------ miles per hour was held for several years. Waterton's description of the tendency for the aircraft to roll was indeed harrowing as he had to use full aileron to maintain the wing in the level position. It appeared to me to be a very "dicey do" as it could have been catastrophic due to the aero-elastic distortions that must have been taking place caused by the combination of "high q" dynamic pressure in excess of 920 pounds per square foot and the shift in the centers of pressure of the surfaces; wing, tailplane and even the fin along with the loss of some of the effectiveness of the control surfaces. In those days the effects of aero-elastics in the high sub-sonic flight regime was not fully understood and there occurred a number of fatalities that were difficult to pin-point the exact causes. We were able during the design phase of the CF-100 to consider these effects on the airplane structure and successfully over-come any deficiencies that may have arisen due

to this phenomena; except for one rather minor case which was easily corrected by resetting the angle of incidence of the tailplane (described later).

Returning to the CF-100 flight trials, we started the taxi tests on 17 January, 1950, and unlike the tribulations that we had to cope with during the Jetliner trials, we had favorable temperatures, cold which meant that the jet engines were delivering greater thrust and the runways were in excellent shape so that it was possible to feel the controls with a short airborne "hop" and still stop well within the end of the runway. We did experience a minor problem in that at near take-off speed the auxiliary nose wheel door that was located behind the nose wheel strut was being pulled forward by the suction caused by the turbulence set up by the strut and the forward door. This was not suppose to happen as the designer had assumed that the force due to the air pressure "q" would constantly keep the auxiliary door in the open position until the nose wheel retracting mechanism was activated and it would engage the door and pull it shut as the nose wheel entered the wheel well. This posed a dangerous situation as the auxiliary door would have been jammed by the retracting nose wheel assembly leading to a possible "wheels up" landing. Jim Floyd at the time was standing in for John Frost who was absent came up with a "fix" which consisted of a positive latch which removed the hazard. This was accomplished within two days. Very clever!

The first flight took place two days later, on 19 January, 1950 and lasted about 40 minutes. In order to assess the handling at the lower speeds (and perhaps we were still a little landing gear "shy") the flight was carried out without retracting the landing gear. On the second flight the landing gear was retracted and extended several times as the flight speeds were increased. Now our problems really began. Bill Waterton made some speed trials and since we still did not have the flight test instrumentation installed, we had to rely on the figures from his pilots notes, such as they were, to perform the necessary calculations to derive the true maximum airspeed. This turned out to be equivalent to Mach 0.88 which in no way was possible. During the CF-100 design phase I had calculated that the maximum speed in level flight would be Mach 0.835 and that due to the rapid rise in the wing drag coefficient with Mach Number even to reach Mach 0.85 would require an increase in engine thrust of over 50 percent to that available from the jet engines. Just no way! Unfortunately managed ignored us as they wanted to make the most of it and reported to the airforce that the CF-100 was capable of exceeding its specified speed by 30 miles per hour. I don't why the engineering department didn't speak up and save the management's embarrassment of having to retract on this one when later on in the program with the installation of the instrumentation in the aircraft we were able to determine that the maximum all out speed was indeed Mach 0.835, 551 miles per hour at 36,000 feet and not 580 as recorded in Waterton's notes. Even then doubts still persisted in management's mind, wishful thinking, until we took the CF-100 to the United States Air Force's Wright Patterson Field for an evaluation by their pilots and engineering staff. One of their test involved the determination of the aircraft's maximum speed where they used a specially calibrated intercepter to pace the CF-100. Again the maximum speed was determined to be Mach 0.835. More about the U.S.A.F.'s assessment later.

It became apparent that we could expect little constructive testing and development while Waterton was the only person allowed to fly the CF-100. The company had hired a very competent test pilot, Bruce Warren to take over when Waterton was through. Unfortunately Bruce never had a chance to take the controls which were only installed in the front seat and was relegated to the rear seat through-out the entire stay of Waterton. Waterton would only fly when ~~it was~~ it suited him, which meant that a great deal of available flight time was lost due to his attitude. He repeatedly stated that he felt that the aircraft, or ~~was the other way~~, that the other pilots were not up to it. He received a great deal of publicity in showing off the CF-100 to dignitaries at the plant and at demonstrations in Ottawa and Boston. Bruce served him well as he did fulfill the role as navigator and they always arrived at their destinations without getting lost. It was a far cry from the type of co-operation that we got from Jimmy Orrell. Waterton would never adhere to the test plans that we issued to him with the result that the recorded data was very difficult to unscramble and derive meaningful engineering results. I can categorically state that throughout the entire Waterton controlled flight test period very little was accomplished and that later the company was to pay dearly for the lost time in the program and the delays in coming to grips with some fundamental problems that showed up later on. The R.C.A.F. had assigned two of their best test pilots, all the pilots that were in "waiting" to fly were all graduates of the Empire Test Pilot School in England which was considered the tops in the western world, to test the CF-100 on behalf of the service who really owned the aircraft. These two officers, Paul Hartman and Shan Badeaux showed remarkable constraint at Waterton's refusal to let them fly the aircraft because he felt and did state that they were not qualified to tackle such an advanced machine, and they would be risking their lives and the aircraft. Management did little if nothing at all to instruct Waterton to let them and Bruce Warren to take over the controls. After all they were qualified and this was their profession.

I by this time was completely frustrated and arranged with both Hartman and Badeaux that I would take it on my own to prepare the aircraft for them to fly on a particular Sunday. In effect it was a conspiracy behind Waterton's back. I desperately needed data from properly controlled test flights and these two gentlemen agreed that they would back me up with their superiors in the event that Waterton were to choose to make an issue of this. It must be remembered that we were about 8 to 95 months into the flying program and had very little to show for it.

The weather was ideal and the two pilots racked up 3 flights each for an unheard of a total of ten productive flights all in one day. Mid way through the flying, Waterton heard the noise of the jet flying overhead from his room at the Royal York Hotel and jumped into his car and came to the plant. He immediately accosted me, grabbing me by the shoulders and berated me for allowing the two pilots to fly the aircraft so frequently that they would surely suffer from fatique that could lead to an accident! I told him that they knew what they were doing and turned away. This incident finally broke Waterton's exclusive hold on the Cf-100 program. At this time we still had not resolved the matter of Mach 0.88 versus 0.835 and the data from these flights finally verified what I had known all along that it was Mach 0.835. I really did wish that it could have been the other way, but that was only wishful thinking.

Meanwhile arrangements had been underway for the CF--100 to be flown to Wright-Patterson Field in Dayton, Ohio for an evaluation by the United States Air Force. Waterton was originally slated to take the aircraft there and show it off, but due to a queer quirk his security clearance was delayed, this was to be an airforce to airforce operation and under the jurisdiction of the Canadian Government. Waterton's clearance never came through in time for this operation and the evaluation was performed without his participation. I don't remember the date of that operation, but it must have been late in 1950.

Bill Waterton returned to England early in 1951. He did make a valuable contribution to the CF-100 program in tracking down a few short-comings, but it took so long and my criticism is that the development of the CF-100 was painfully slow, and could have been accomplished inside of several months rather than the better part of a year if only he had worked as a team member and not as a "prima donna". Later I heard from a very reliable source out of Gloster Aircraft in England that when the flight test crew there heard that Bill had been selected to go to Canada, there was a great cheer since they felt that a major impediment to their development work had been removed and finally they would make some real progress on their Javelin fighter. Unfortunately it was a case of too little and too late as its production was limited to a few aircraft. Again this was partially due to the time delays involved in sorting out the aircraft problems. Waterton's slow performance on the CF-100 appeared to be a re-run of the Gloster saga.

Recap:

A plus for Waterton was that he did make the initial flights on an aircraft designed and built though by a dedicated team, we were none-the-less still maturing. There were some deficiencies that probably would not have occurred had we all been more experienced. He did contribute to the correction of some minor short-comings and did do the initial trials on the defunct dive-brakes and strongly recommended that they be changed. This we already knew as the chief engineer had, during the latter part of the design phase, authorized a second set of wings to be built with the new dive brakes (my design) and thus managed to mimimize the down time. When Waterton deployed the original brakes the CF-100 not only pitched but was accompanied by considerable buffeting which, although still controllable ruled out their use as the condition would drastically detract the operation of armament such as aiming, rocket and gun firing. The buffeting might of, in due course affect the structural integrity of the aircraft. It only took one flight to reject this design. The new wing with the finger type of airbrake was quickly accepted by Waterton since the aircraft exhibited none of the characteristics experienced with the original air brake design. Scrap one set of wings and some lost time. As a result of high speed dives which exceeded the placard speed of Mach 0.85 which took place in 1952, a restriction was placed on the operation of the new dive brakes which will be discussed later.

Long Range Fuel Tanks

For ferrying purposes the CF-100 was equipped with two wing tip fuel tanks with a capacity of 338 Imperial gallons each. I was concerned about the adverse effect that these tanks would have on the longitudinal stability of the CF-100 since no fins had been installed on the aft end of the tanks. This was not any genius on my part, but I had observed similar fin arrangements on some of the contemporary aircraft and for a while I was puzzled about their use. It finally dawned on me! The wind-tunnel tests conducted on the rigid CF-100 model with the tip tanks did not simulate the wing flexibilty of the actual aircraft with the result that the vortex flow emitted at the wing tip trailing edge produced a downward force which increased with the angle of attack of the wing as might be experienced by a change in flight attitude such as a pull-up, an up gust or in a turn that would further increase the angle of attack of the wing. This force would cause the aircraft wing to twist further increasing the angle of attack. This would result in a falling off or reduction in the force applied by the pilot on the control column. In the worst case if the pilot was not devoting his full attention to this event could result in a stall. The pilot would nevertheless would have to concentrate on counteracting this tendency and it would put an added burden onto his flight duties. The application of the fins changed this downward force to an upper force due to the vortices

PITCH-UP DUE TO WING TWIST.

being shed at the wing tip to impinge upon the fin in such a manner to cause the tip tank assembly to rotate nose down as the aircraft angle of attack increased. This was a bonus as the inherent longitudinal stability for both "stick fixed" and "stick free" of the CF-100 was increased over that which existed for the aircraft without wing tip tanks. This meant less fatique for the pilot when flying long ranges. The tip tanks were not jettisonable.

The Fictitious Bumps

Another ridiculous problem surfaced whilst we were preparing the aircraft Number 18102 for long range flight trials in the hopes of flying the CF-100 across the Atlantic ocean to show off the aircraft at the annual Farnborough Air Show held late summer in England. The engineering department had issued a memo that as a result of their analyses and ground resonance (shake) tests that there was a very strong possibility that the with the wing tanks loaded with fuel that the wing would break off if during the take-off run the CF-100 wheels were to encounter a bump. The probability of this catastrophic event was directly proportional to the height of the bump and the number of bumps encountered during the ground roll. The letter which was signed by Jim Chamberlin went on to state that the probability of the wing failure was about 30 % for a one inch bump increasing to 100 % for a 12 inch bump. We in flight test had no quarrel with the 12 inch bump as we were quite aware that if the aircraft were to encounter such an obstacle the entire airplane would be wrecked!

I believe that the ground resonance tests and analyses was performed by John McKillop, who was a specialist in aircraft flutter and reported to Chamberlin. (In fairness to McKillop his credentials were sound as later in years he was awarded the Wright Brothers' medal. Unfortunately he lost his life while performing flutter flight tests on a DeHavilland airplane in the 60's.) Don Whittley who was in charge of flight testing did a bit of "snooping" in the engineering office and came to the conclusion that the technical conduct of the tests was suspect, especially in the selection of the damping for the aircraft structure during the test. These details now escape my memory. What was particularly annoying to me was that the memo offered no solution. My annoyance was further compounded by the panic it caused to the management, in particular the Chief Engineer Edgar Atkin and the Chief Designer John Frost. I was not exposed to the President's comments or state of mind. It must be remembered that here we had an urgent situation that required the tip tanks to enable the aircraft to meet a commitment that the company was about to make for the CF-100 to show its "stuff" to the aviation world. It was also important for Canada to show the "flag" in that we were now capable of designing and producing a viable product and were no longer just hewers of wood and carriers of water.

Getting back to the problem that we had inherited. Bruce Warren who by now had been assigned as development test pilot on the CF-100 entered the fray and challenged the infamous engineering memo, by responding with criticisms of his own. With his support I stuck my neck out and decided to take some positive action. I instructed the ground crew, who reported to Jim Kenny, Manager of Experimental Shop, to install the wing tip tanks and later on I would issue further instructions concerning filling the tanks with fuel. This was important since I wanted the aircraft to be moved out of the hangar with no fuel in the tip tanks since in order to move the aircraft out of the hangar meant that the aircraft wheels would have to traverse the hangar door rails which were several inches high. Meanwhile we arranged a series of one inch planks to be placed at random on the aircraft taxi strip and in order to minimize the risk we would tow the CF-100 by means of a mobile unit (mule)over the boards at various speeds. The memo had stated that the speed of traversing the bumps was not the critical factor. The size and spacing of the bumps were! I had informed my superiors of my plan of action which worried them even more but they did not tell me to cease. At least they had a scape-goat! I was informed that the aircraft was ready and parked outside the hangar on the taxi strip. I hurried down to the taxi strip and asked the crew chief to fill the tip tanks with fuel. To my shock, which quickly turned to elation, he informed me that they had followed their normal procedures and fueled the aircraft while it still was inside the hangar and then towed it out with mule. For once I was glad that they hadn't followed my request to the letter, since in their innocence, tough guilty action, they had just demonstrated that there was no problem as they had already towed the CF-100 over a series of not one but two inch bumps. We went ahead and performed the planned tests over the planks. I then had Bruce Warren power up the CF-100 and perform a series of low speed runs over the planks. There was absolutely no indication of wing oscillation; it was rock solid. I then phoned the Chief Engineer and his staff who were conspicuous by their absence to come and witness further trials. They arrived on the scene and I climbed up on the wing and sat on the tip tank while Bruce Warren taxied the aircraft. This was probably a foolish stunt on my part, and it served no useful purpose other than to further sour relations between design engineering and flight test. I just had to vent my frustrations as we had more than enough real problems to tackle and solve without chasing these types of red herrings. This irresponsible action on the part of Chamberlin was similar to the flap that he caused on the Jetliner fin assembly flutter just two days prior to a demonstration that was to be held in Ottawa for top government and foreign dignitaries. Again the management was to all intent and purposes held hostage on this case which turned out to be false. This incident is discussed under the Jetliner flight test musings.

On account of the fatal crash of the second aircraft 18102, the CF-100 did not make the Farnborough show that year which contributed to the conclusion that in spite of the acceptance of the validity of the long range fuel tanks, the CF-100 was not truly ready to undertake the transatlantic flight and that the stage of development with the interim Rolls Royce Avon engines did not represent the CF-100 which was to be equipped with Orenda engines was not the aircraft that the company wanted to market. This was in part due to the time lost on the program by Waterton's reticence in pursuing a diligent and active flying program, by refusing to fly when it was not to his convenience and prohibiting the other pilots-in-waiting to participate in the testing. The rest of the blame can be spread around to all participants from top management down as we were all relatively new to this game and times were changing, especially with the progress occurring in the rest of the aviation industry.

To this end Bob Lindley, who recently arrived from A.V.Roe Manchester, England via Canadair in Montreal prepared a CF-100 development plan which recognized the limitations of running an aircraft program based on a couple of proto-type aircraft. In his plan he proposed somewhere up to 16 CF-100's be allocated to development testing , covering the complete range of systems, performance, structural, navigation, fire control and armament, trial installations, with the prime purpose of carrying these functions in a parallel manner instead of serial and thus achieve maximum return on flight hours. It should be understood that in order to conduct many of these tests considerable pre-flight preparation was required, as much as several months of down time. He deserves a great deal of credit for proposing this somewhat radical approach to management and finally received their approval. This was the salvation of the CF-100 program, and helped to restore credibility by the RCAF on the company's efforts. I later realized that many U.S. companies designing and building military aircraft had also selected a similar approach.

Bob Lindley carried this philosophy trough to the Arrow program where-in a quantity of pre-production were allocated to the flight development program right from the start. A point in favour of the Arrow was that by that time, Avro Canada was much more mature having realized the importance of conducting an in depth design engineering program ranging from subsonic to supersonic wind tunnel testing on a variety of models, supersonic rocket launched models, computer analyses for structures and systems, the establishment of a comprehensive ground test facilities including structural loading of portions and the complete aircraft, control response and integrity, fuel flow at elevated temperatures, pilot's cockpit with all controls and feed-back through analog simulators, fatigue testing and so on. The purpose was to ensure safety and success during the design phase so that the subsequent flight tests were in essence to "verify the predictions" so that we would not get a repeat of many of the "gaffs" that had occurred on the CF-100 program!

Tragedy: Bruce Warren and Bob Ostrander

As part of the preparation for the Trans-Atlantic crossing, we were undertaking a series of long range flights to determine the fuel consumption and to obtain flight time to give us confidence about the validity of the operation. We had made several long range flights and on this particular day, Thursday April 5, 1952 the planned route was to fly west from Toronto to Windsor perform a 180 degree turn and overfly Toronto on to Quebec City, do another 180 degree turn, and if all was well overfly Toronto a second time to Windsor and the return to Toronto. A total distance in excess of 2000 miles. On that particular April morning the weather was ideal and I drove over to the end of the tarmac leading to the airport runway to see the CF-100 take-off under maximum load. The aircraft was not quite ready and I had an enjoyable chat with Bruce and Bob, and all was normal. I was the last person to see them alive. The take-off went off quite normally and I returned to my office. This was about nine thirty in the morning. About eleven thirty a disturbing report came into the plant about some-one witnessing an aircraft diving into the ground near London, Ontario and our radio contact was lost. Indeed the CF-100 had crashed. By the evidence of the crater in the ground the aircraft must have fallen, presumably out of control all the way from the cruising altitude of 35,000 to 40,000 feet, straight into the ground. There was no evidence that the occupants had tried to bail out and the only conclusion that could be drawn from the subsequent accident investigation was that the crew had probably passed out due lack of oxygen due to a fault in the system or in the pilot's mask. This was never resolved and later on as more test flying took place we discovered, to my horror that even if Bob who was flying in the back seat, ~~that even if he~~ had been able to jettison the canopy that it would have been impossible for him to raise his arms far enough to grasp the bail-out handle of the Martin-Baker ejection seat which was located just above his fore-head. The problem as were to find out that the airflow deflected by the pilot's windscreen re-entered the upper portion of the now open cockpit and its full force impinged the shoulders of the rear seat crew member. As the occupant tried to raise his arms to grasp the ejection handle, the force of the windstream would cause the arms to fling backwards and under no circumstance ~~was~~ would he be able to even pull them forward, let alone reach the ejection handle until the aircraft speed was reduced to about 160 miles per hour indicated airspeed. The other crucial factor was that under the extremely low temperatures combined with the wind chill factors, the arms and hands would be frozen solid within a few minutes. I did hear that there was such an incidence during an RCAF operation where the "second seater" did have one arm frozen when they inadvertently lost their canopy. I've lost a lot of sleep thinking that if the pilot, Bruce Warren had passed out due to a faulty oxygen mask, Bob Ostrander may have been conscious right to the horrible end. We also discovered later on in the program that one of the production CF-100 allocated to flight test had the canopy emergency release handles held in the closed "safe" position with steel locking wire instead of the soft, easily breakable wire. This error would require extraordinary force to pull the release handle in order to jettison the canopy in an emergency. This disclosure still bothers me to this day!

This may be a good time to introduce the problems that we had with the escape equipment and procedures on the CF-100. As a result of the tragedy we became even more safety conscious and embarked on a series of flight trials to check out the crew escape mechanisms and procedures. An effort which was lead by Don Ridler, senior engineering observer, entailed the removal the canopy and ejection cartridge on the rear Martin-Baker ejection seat that was to be occupied by the engineering observer. The purpose of this decision was to permit the observer to reach up and actually grasp the handle while in flight and to prevent the accidental discharge of the observer from the aircraft in the event that the wind effects or other some other effects would lead to pulling the handle. We realized that this decision could have disastrous consequences if some non-related incident should arise requiring a quick bail-out. Nevertheless the engineering observer still felt that this was still the safer way to conduct the flight test. The purpose was to fly the CF-100 at gradually increasing airspeeds with the engineering observer reaching up to grasp the ejection handle. We were able to determine that the top speed at which he could grasp the handle was about 180 miles per hour. Beyond that his arms were thrust outward and at about 250 miles per hour he could not pull his arms back into their normal position, until the pilot quickly reduced the airspeed below 250 miles per hour. Following this test we build a wooden screen to form a shield that would fit immediately behind the pilot's seat. Inside of a day the screen was made by the Experimental shop and fitted to the aircraft. We then repeated the flight and were happy to find that it was now possible for the engineering observer to reach and pull the handle up to the CF-100 placard speed. We immediately had the Experimental shop make a number of fiber-glass screens to fit all of our test CF-100s. At the same time we handed the wooden screen over to engineering so that they could design a proper transparent unit made out of molded plexi-glass. At that time the test were observed by an RCAF officer who was unimpressed because the observer's sight was limited due to the non-transparent screen and did not want them installed. I more or less told him to get lost since we had development flight test program to perform and we were more concerned about safety and could not wait for the

"properly engineered" transparent windscreen which was weeks away from being available. I was incensed about his attitude since the Warren/Ostrander tragedy had left on me a lasting scar. If only we had known earlier!
It was then decided by all that we should take up Mr. Martins's offer (of Martin-Baker) for his experimental pilot Squadron Leader Fifield "Fifi" to actual perform an ejection bail-out from the rear seat of the CF-100. The test was to be performed at 350 miles per hour and include the entire sequence of canopy jettison and then followed by the bail-out by "Fifi". We had preceded this trial by conducting a canopy jettison initiated by the test pilot with no one in the back seat and photographed the entire sequence by flying along-side with the Jet-liner which was to prove to be of great value as we could set-up several cameras as well as the sight-seers. We were able to study the trajectory of the jettisoned canopy and further confirmed the early wind tunnel tests that the canopy did indeed clear the top of the fin by a large margin. Then came the day of the live test with Mr. Martin on board the Jet-liner with a virtual battery of photographers. We flew up to Camp Borden where the actual bail-out was to be performed as the RCAF base had not only plenty of cleared space for "Fifi" to land on, but was adequately provided with accessible emergency and medical services. The test went off like clockwork and "Fifi" emerged from it all with only a slight scratch on his chin.

We had investigated the possibility of modifying the ejection seat by replacing the handle above the crewman's head with a ring located between his legs which would eliminate the need for him to expose his arms to the deadly airstream. There were two main drawbacks to this alternative. First was that in the standard configuration the act of pulling the overhead ring which was attached to a curtain down which covered his face and thus would protect his head, eyes and face from the severe air blast as the seat emerged from the aircraft. Secondly the act of the pulling down the ring and the attendant curtain assured that the crewman's body would be held in an perfectly upright position and thus keep his spine in a straight line to better withstand the high acceleration initiated by the seat cartridge firing. Bending over to pull a handle located between his legs would probably cause the crewman to lean forward with the result that his spinal column would be arched and suffer severe injury due to sudden shock as the seat shot out of the airplane. This investigation was done in co-operation with Mr. Martin who quickly pointed out the deficiencies of the company's proposal.

We were also concerned about the crew being able to get out both in the air and on the ground in the event of a crash landing. The canopy relied on the suction effect of the airstream to lift it off the airplane while in the air. We felt that it might be possible to reduce the precious time left to escape from the disabled aircraft if the crew did not have to first manually jettison the canopy. What we did was to install steel cutters at the highest point of the seat so that as the seat was propelled outward with the canopy still in place, the cutters would cut the thick plexi-glass sufficiently so that it would shatter as the top of the moving seat smashed into the canopy. This also had its drawbacks as remnants of the canopy that were still in place could cut the crewman as he went by. Mr. Martin explained that the act of cutting the canopy introduced a momentarily high deceleration force in the downward direction that could cause spinal injuries. With the crew trapped inside a aircraft on the ground and possibly injured, with the canopy in place posed another problem. The canopy weighed several hundred pounds and the crew because of their cramped quarters could not get any leverage to lift the canopy. We tried installing an ax so that the crew could in effect chop their way out. This didn't work due to the strength of the plexi-glass and again due to the cramped space it was not possible to really swing the ax; it just bounced off and only provided an addition hazard of striking the ax wielder. If I remember correctly all these schemes were abandoned. The cutters on top of the seat provided a small hazard as both ground and air crew could cut themselves as they moved around the cockpit. I don't remember if the cutters and ax were retained as standard equipment. They may have been.

During the live ejection trials, I was able to spend some time with Mr. Martin, who was quite open and frank about his background. He was quite portly and made a joke of it. I asked him about Mr. Baker of Martin-Baker and he informed me that Baker was dead. Apparently these two gentlemen had been very active in fighter aircraft design and according to Martin they had designed and built an aircraft that was in the Hurricane/Spitfire class. Since they were a small company compared to Hawker (Hurricane) and Supermarine (Spitfire) they were not taken as seriously as he felt that they deserved. Anyhow Baker was also a test pilot and shortly after becoming airborne the engine failed, the aircraft crash landed and caught fire killing Baker. Martin witnessed the entire event and to the present he could not stand the smell of cooking meat since it reminded him, actually it made him ill, of the odor emanating from the burning aircraft with Baker's body. He made up his mind that if Baker had had a rapid method of escape that his life would have been spared. It was this incident that provided the motive to enter into the development of the ejection seat which was later to save many lives and for many years was the number one escape system in the Western world. He also went on to say that in light of the relationship that they had, the name Martin-Baker would never be changed and the Baker's heirs would always receive his share of the profits. There obviously a great bond linking these two partners.

United States Air Force Assessment at Wright-Patterson Field. As mentioned earlier we in conjunction with the RCAF took the CF-100 to Wright-Patterson AirForce Base at Dayton, Ohio to let the USAF perform an evaluation. A number of young test pilots flew the aircraft (it wasn't so difficult!) followed by several test flights by the base commander General Boyd. During the earlier flights the fairing located at the wing leading edge root adjacent to the engine nacelle wrinkled due to the wing deflection caused by the pilots subjecting the CF-100 to high "g" manoeuvers. This lead to the onset of buffeting at high Mach Numbers so that the pilots were unable to assess the full potential of the CF-100. For General Boyd we smoothed out the wrinkles and covered the entire fillet with doped tape. This apparently did the trick and he was able to achieve maximum level speed of Mach 0.835 which was verified, for the first time by means of a speed calibrated interceptor flying along side. When asked about his assessment of the airplane he kept dwelling on the responsiveness and performance of the Rolls- Royce Avon engines which were far superior to the USA engines. The CF-100 itself did not receive such praise, although he did not have any criticisms about either. Their assessment was worth the effort since we were made aware of the sensitivity of the effect of the wing deflection and fairing distortion on the performance of the aircraft. We were able to get them to agree to bring their pacer aircraft to AVRO and check out the airspeed system of the Jetliner and at the same time participate in its flights.

Following the return of the CF-100 back to the plant, we in flight test embarked on an investigation program as to how we might improve not only the wing leading edge root fairing but the viability of incorporating a new fairing between the aft engine nacelle and the fuselage. This effort was nipped in the bud by engineering management who decreed that it was the prerogative of the engineering office design team. Although they did very little along the lines that we had embarked upon, we were able to pass on to the designers data that Don Whittley had obtained from Northrup Aviation who had stressed the importance of avoiding compound curves for our leading edge fairing and strongly recommended that the wing root/engine nacelle fairing be redeveloped in such a manner to allow the wing to actually move independently of the nacelle, and stressed the fact that the nacelle surface at the wing juncture should always be normal to the nacelle surface. This approach would avoid the development of pressure peaks occurring simultaneously at the same location which would lead to an early breakdown of the airflow and lead to additional drag and buffeting. This phenomena would also degrade the amount of "g" that could achieved at the higher angles of wing incidence. This approach was eventually adopted by engineering design on the Mark IV.

Enter Peter Cope and Jan Zurakowski

Following the accident of 18102, Peter Cope, a graduate of the Empire Test School, left England to join Avro Canada. Later on Jan Zurakowski for personal reasons left Gloster Aviation to join us as senior development test pilot. England's loss was our gain. These two gentlemen really made the tempo of our CF-100 program hum. Don Rogers the Chief Test Pilot could only give a limited amount of time to the CF-100 program as he and Mike Cooper-Slipper were both deeply involved with the JetLiner. Mike was assigned later as chief engine development test pilot for both the Orenda and Iroquois programs flying the modified Lancaster with the two outer reciprocating engines replaced with two Orendas, the Orenda equipped F-86 Saber and the B-47 bomber with a single Iroquois engine installed on the aft side of the fuselage. As the Jetliner program waned Don Rogers spent a great deal of his time flying the CF-100 on the icing program.

Both Peter and Jan would eventually devote their full time on the Arrow program and the company hired Chris Pike, Glen Lynes and Stan Haswell who was transferred from my group where he had been hired as a flight observer.

Wing Failure

Probably the greatest embarrassment, let alone seriousness to Avro occurred on the early Orenda equipped CF-100. The RCAF had taken delivery of the first preproduction CF-100, (No. 18104) on 17 October, 1951 at a ceremony which was attended by a number of Government dignitaries and ministers including C.D.Howe, Brooke Claxton and Air Marshall Wilf Curtis and Sir Roy Dobson who had come over from England for the event. Within days of the delivery, the wing skins began wrinkling on this aircraft and the other Cf-100s which were being test flown prior to their delivery. Apparently the "fix" that had been incorporated on these aircraft did not work and a panic ensued as the RCAF had returned No. 18104. The full resources of the Hawker-Siddley group were turned on to find a solution which in the end was achieved by a brilliant Avro Canada engineer, Waclaw "Vass" Czerwinski (many years later "Vass"and I became close friends as he was of incalculable help to me while I was associated with Indal on the Helicopter Recovery Systems) who designed a simple pin joint which isolated the main former around each engine from the flexing main spar under load. Once incorporated the problem disappeared and the CF-100 was structurally sound. This modest talented engineer and a few others, though not of quite his equal, were the unsung heroes that made Avro a technical success. It's too bad that the technical success was not matched on the management side.

The CF-100 Mark 5 Development

1. A program was undertaken by Avro Engineering to improve the performance of the CF 100 Mark 4 aircraft, in particular to raise the service ceiling. A concerted drive in the field of weight control resulted in the reduction of the operational weight by about 4000 pounds in spite of an extension to the outer wing panels. This was accomplished by the removal of non-essential items (why they were no longer essential is a moot point) and by a reduction in the fuel capacity. Outer wing panels were added at each wing tip which increased the wing span by approximately seven feet. Extensions were also added to the tailplane to maintain similar longitudinal stability characteristics. The resulting increase in both wing area and aspect ratio were designed to give a reduction in drag (particularity induced drag) at high altitude and a corresponding increase in service ceiling. The aircraft which incorporated these modifications became known as the CF-100 Mark 5, and substantial performance gains were demonstrated when compared with its predecessor, the CF-100 Mark 4.

In the interests of clarifying the two Marks, the differences are listed below:

	Mark 4	Mark 5
Wing span		

Even before the CF-100 Mark 5 reached the flight stage members of the Flight Research Section of the National Aeronautical Establishment in Ottawa (N.A.E.) and the Flight Research and Development Department at Avro, the two groups enjoyed a mutual respect, which unfortunately was not the case with the Engineering department (personality clashes for reasons unknown to me and which in the long run was to have a negative impact on the Arrow program when A.V.Roe needed all the support and friends in the Canadian Government that it could muster when the going got tough. I believe that had this situation been amicable the Establishment might have helped us in our struggle to save the Arrow. There were numerous occurrences between the company and the National Aeronautical Establishment during the Arrow design and development program that further deteriorated this relationship, or lack of. (If I ever get around to it I will discuss some of the incidences that I became aware of.)

The close cooperation between N.A.E. and our flight test group resulted in not only achieving even greater performance gains than the Mark 5 was able to produce (it could have been applied to the Mark 5 itself which would have resulted in even greater operational performance) as well as being able to achieve supersonic speeds in dives with complete aircraft control, more on this later, whereas the Avro Engineering department stated that it was absolutely impossible based on their analyses and supersonic wind tunnel tests that were carried out at the Cornell aerodynamic test facilities on the CF-100 test model. TUNNEL CHOKE!

I am probably duplicating some of the earlier statements, but our cooperation with N.A.E. lead to three areas aerodynamic development:

1) Use of modest flap and aileron TRIMMING angle deflection at altitude to increase the service ceiling and the enhance the maneuverability at these high altitudes(this was our work).

2) Application of vortex generators on the wing to substantially delay the onset of loss of lift due to critical Mach number (N.A.E.'s work).

3) The stability and control of the CF-100 at transonic and supersonic speeds (this program was carried out by N.A.E. using a small semi model of the CF-100 Mounted on the upper surface of their F-86 wing where at high Mach numbers the local flow became supersonic even when the aircraft was flying at subsonic speeds. This phenomena was much more representative than the Cornell tunnel since the model was in "free stream" whereas in the supersonic wind tunnel the conditions were plagued with wind tunnel tending to "choke" leading to dubious results.

4) By pooling our mutual resources we were able to capitalize on our findings and achieved the following;

a) Increase the performance of the Mark 4 by the simple additions of vortex generators and flap and aileron angle "droop" so that it surpassed that of the Mark 5. Again these modifications could have been applied to the Mark 5 thus further improving its performance.

and b) Achieve supersonic speeds in dives thus determining the aircraft characteristics for supersonic flight and methods of recovery in the event that the pilot may have inadvertently gotten himself into such a situation by exceeding the placard speed Mach 0.85 and to recover safely.

Description of the Devices

1) The deflection "drooping" of the trailing edge flaps and the ailerons

a) Trailing Edge flap

The trailing edge plain flap was deflected through ten degrees and, in this case some improvement in performance was immediately apparent. Not only did flap deflection provide a means whereby the buffet lift coefficient could be increased, but it also gave a configuration which, for the same lift coefficient, showed a substantial reduction in drag.

The former result was anticipated and the lift gains corresponded roughly to the low speed values. Deflection of the landing flaps generally, however, incurs an increase in drag, and the natural question was: "Where did the reduction in drag come from?" This was a rather unusual situation; one is usually required rather to diagnose the increase in drag! The ceiling of the aircraft was increased by approximately 1500 feet and the maximum speeds at high altitude was also slightly improved.

Why the drag reduction?

It was suggested that a change in spanwise, due to flap deflection could account for a reduction in drag or, again that the reduction in the angle of attack of the nacelle and fuselage would account for it. Don Whittley with the aid of D. Kuchemann of the Royal Aircraft Establishment R.A.E. describes the interaction of the shock wave on the upper surface being manipulated by the introduction of a small degree of landing flap angle that reduced the wave drag more than the increase in wing profile drag due to the same amount of flap deflection which resulted in a net overall reduction in drag. (See Reference D. Whittley's paper in the 1958 issue of the Royal Aeronautical Society entitled " Flight Development of the Avro CF-100 Mark 5 aircraft" for an elaboration of the Kuchemann theory.)

Flight test provided an indication that the increase in profile drag due to a small flap deflection was itself small. Tufts on the upper surface of the trailing edge flap remained quite smooth with a flap deflection of only 5 degrees, at 10 degrees the tufts became turbulent, and at 15 degrees they were quite unruly. It is reasonable to suppose that very little profile drag penalty would be incurred with 5 degrees flap, an appreciable effect with 10 degrees flap, and an over-riding effect at 15 degrees.

The two effects described above conflict, and the overall drag falls and then rises again as the flap angle is increased. Flight test results were used to find an "optimum" position of flap angle, that is, one just beyond the point of minimum drag, which then provided also an appreciable gain in lift available. We also "drooped " the aileron a few degrees an achieved an additional bit of gain. Since this gain was modest and the mechanical complexity involved in rigging the ailerons to main their effectiveness in their primary role we did not pursue this any further. The test pilots did remark that the drooped ailerons produced a marked unpleasantness in handling.

We also deflected the leading edge nose since it was hinged at the lower surface to gain access to the wing surface. We deflected the nose flap through small angles with a suitable fairing to maintain a smooth wing contour. Tests were conducted at high altitudes, but with no perceptible improvement. We really did not expect any gains.

The foregoing considerations apply to flight at high altitudes and high subsonic speeds.

Vortex Generators

Vortex generators are small stub-like wings place in a row spanwise, usually on the upper surface of a wing. In our application they were made of aluminum strip bent into an angle to facilitate installation on the wing surface. Vortex generators stir up the boundary layer air and, in this way, alter the character of the interaction which takes place between a normal shock and the boundary layer on the wing surface at transonic speeds. Again I refer the reader to D.C. Whittley's paper referenced above for the theoretical description of the various types of vortex generators and their effect on wing shock wave and boundary layer. The research work accomplished by the N.A.E. group covered the installation of their large vortex generators located spanwise along the wing and at 9 percent to 30 percent of the wing chord. Their tests clearly indicated that the effectiveness of the vortex generators increased as they were moved forward along the wing chord, however the drag also increased accordingly. They found that the 9 percent location produced the best effect. We had mutually agreed that their large vortex generators might be made smaller in the hopes of reducing the drag with minimum loss in effectiveness. Upon receiving a sample of their design we immediately embarked on a program to minimize their size and were successful in substantially reducing the overall drag with only a small loss in their effectiveness. Our flight tests also verified that the installation of vortex generators did indeed increase the drag of the CF-100. The extent of this drag increase was proportional to the size, spacing and forward chord location of the vortex generator.

By trial and error we were able to select a small generator that still was quite effective and located these vortex generators at the 9 percent chord station. We also found that a larger vortex generator was necessary and very critical which was mounted at the 9 percent chord point adjacent to the nacelle. If this particular vortex generator was not installed we would lose the complete effectiveness of the entire vortex generator installation. The total complement of generators comprised the large one at the wing nacelle juncture plus approximately 35 small vortex generators all the way to the wing tip. A most peculiar phenomena which we were unable to rationalize, mostly due to the urgency of getting on with the program and achieving our goals of improving the CF-100's performance at altitude. Our flight trials did prove that the installation of the vortex generators did substantially increase the available lift coefficient at the high Mach numbers.

We then combined the use of the vortex generators and set the landing flaps at various settings and continued our flight trials. To our amazement this combination produced the most remarkable results. With the landing flaps set at 10 degrees and vortex generators installed as described above we were able to increase the maneuverability of the CF-100, Mark 5, at 40,000 feet and at a weight of 29,500 pounds at a Mach Number of 0.82 from 1.38 "g" to 2.5 "g". In other words this meant that the CF-100 radius of turn was approximately halved!

The "g" values for various Mach Numbers are listed below:

Aircraft Weight 29,500 pounds
Altitude 40,000 feet

Mach Number	Basic CF-100 MK5	10 Degrees flap only Flap	10 Degrees & Vortex Generators
0.60	1.6	1.72	1.87
0.65	1.79	2.0	2.1
0.70	1.87	2.08	2.22
0.75	1.79	2.06	2.33
0.80	1.59	1.94	2.44
0.82	1.38	1.75	2.49

The RCAF did conduct some trials of their own on a vortex generator equipped Mark 5 as described in pages 95 and 96 of Larry Milberry's book " The AVRO CF-100". To quote:

"" In mid 1957 there were also trials with wing tip extensions, rocket pods and vortex generators(small strakes on the upper wing surface near the leading edge which smoothed the air flow over the wing). With the aircraft at 33,500 lb. the vortex generators increased the ceiling from 37,000 feet to 40,000 feet for the conditions of the particular flight. On the other hand ground run increased by some 100 feet and the stall speed by 3 or 4 knots. Aerodynamic ceiling went from 49,200 feet to 53,000 feet. CEPE Report 1292 notes: " The addition of the vortex generators has greatly increased the maneuverability at high altitude but more powerful engines would be required to take full advantage of the potentialities offered." The vortex generators were not to be used operationally on the CF-100."" Neither Don Whittley nor myself, the main principals of this project were aware that the RCAF had conducted these trials. I can only presume that our presence was not wanted. Perhaps we would have persuaded the RCAF to reconsider their decision and maybe we could have worked a method of reducing both the increase in the take-off distance and stall speed because we were both very familiar with most of the factors that may have had an impact on these performance values.

CF-100 Performance Improvements Base-Line Mark 4

There were a number of proposals put forth to improve the performance of the CF-100. In a few cases, we were able to demonstrate the improvement to the performance by means of flight tests. Even though these demonstrations were successful, we were not able to get the RCAF to adopt them. I believe that the solutions were either too simple ~~resulting~~ (since the cost of the minor modifications would add nothing to the "bottom line") or that the schemes had been conceived in flight test without the benefit of engineering's blessing and received no support from the company as a whole since we did not have the clout to influence management without receiving engineering approval.

The proposals are listed below.

Proposed by engineering.

1) Increase the wing span by adding extensions to the wing. This proposal was accepted and the aircraft became known as the Mark 5. The modifications consisted of two rectangular wing sections that were feet chord and 3.66 feet in length (span). This modification to the wing span and area required that the span of the tailplane be increased to 25 feet to maintain adequate stability. Since it was not fortuitous to make a major alteration to the wing itself and supporting fuselage/ nacelle structure, engineering managed to get the RCAF to reduce the maximum acceptable flight load factor " g " from 7. to 6.0, approximately. In effect that this modification was like taking two steps forward and one backward since the increase in wing area and aspect ratio did enhance the performance with respect to rate of climb and an increase of about feet in the service ceiling, there was a negative effect of the added increase in the CF-100 weight due to the additions of the wing and tailplane panels. In no way could the load factor be brought up to the original specification without a major redesign along with a major weight increase. It was my rather biased opinion that this was an example of increasing the price, and therefore profit on the part of the company.

I know of two fatal accidents that occurred on the Mark 5 due to pilot unfamiliarity of the Mark 5, limitations.

The first fatality was that of Avro test pilot Glen Lynes who was performing aerobatics (trying to achieve the "Zurabatic Cartwheel") on a partially modified Mark 4 which had been equipped with a Mark 5 enlarged tailplane. The wing panels were in short supply due to production delays and in order not to interrupt the production run a number of CF-100's were coming of the production line equipped only with the enlarged tailplane. Apparently the pilot did not appreciate the difference in handling and during a pull-out from a dive he did not allow for the increased pull-out radius and crashed into the ground. He did manage to eject but was too late for the parachute to deploy.

The second fatality occurred during an air show. In this instance the pilot was making a high speed fly past and did a rapid pull-up. As the CF-100 was climbing the "g" forces exceeded the design limit and the wing broke off about midway along the aileron span. This was a human error since some-one had failed to put the required ballast in the rocket pods which was necessary to alleviate the excessive high wing load during high "g" operations. In order to alleviate the high up loads on the wing caused by high "g" manoeuvres the dead weight of a loaded rocket pod which would be subject to a downward load of its weight times "g" had the effect of permitting the higher loads to be applied with impunity, possibly by about 1.5 to 2 "g".

2) Another proposal offered by AVRO was the replacement of the CF-100 wings which had a thickness ratio of 10 % with a set of wings with 8% thickness ratio. This change required that the tailplane be also replace with one of 6 % thickness ratio.
On the positive side this meant that the CF-100's maximum speed would increase from Mach 0.835 to Mach 0.88-0.90.
On the negative side the maximum service ceiling was lower by several thousand feet due to the added weight increase of the thinner wing and tailplane components. We in flight test were somewhat appalled when we became aware of engineering's proposal. We, in flight test including the test pilots, Zurakowski and Cope who had been in combat, believed that increasing the altitude and manoeuvrability at altitude was much more important than a speed gain of a mere 0.06 of Mach Number which corresponds to a velocity of 0.06 times 660 mph equals 40 miles per hour. When we queried engineering how the CF-100 could intercept and shoot down a bomber at a higher altitude, the response was that the CF-100 would be equipped with missiles that upon being launched would climb and seek out the target and thus destroy it. The increase of 40 miles per hour over the Mark 4. CF-100 would enable the interceptor to better position itself for the actual missile launch and trade off the speed by doing a pull-up to enhance the missile performance. It must be remembered that this was in 1956 and the existence of such missiles were only on drawing boards. We felt that it was much more important that the interceptor have an altitude advantage over the bomber target as the then current weapons, guns and unguided rockets would still be effective. If the interceptor were to have an altitude advantage it could be traded off for speed by diving the aircraft. Fortunately the RCAF did not buy it, as they were looking forward to the Arrow which was in a class of its own.

Schemes proposed by Flight Test

3) Wing flap droop.

I cannot recall where the idea of using limited amount of flap angle droop originated. However we jury rigged the flaps so that we could obtain various degrees of droop, 5, 10 and 15 degrees. Lo and behold we were able to increase the service ceiling of the CF-100 by several thousand feet. The optimum setting appeared to be about 10 degrees. The drag penalty at 15 degrees fla[droop was unacceptably high. We went on further by drooping the ailerons as well, 7 degrees, and obtained an additional gain in altitude. Since the test conditions were jury rigged, we had to drop the aileron droop as flying with 7 degrees aileron droop presented an unpleasantness to the pilot. If we could have obtained engineering approval for this scheme the unpleasantness of the drooped aileron could have been dispelled if through the use of an irreversible power aileron system. In fairness to management the aileron power system probably was not worth developing so late in the CF-100 production cycle.

As usual engineering questioned the validity of our measurements and in order to put the matter to bed for once and for all we resorted to a bit of brinkmanship. As there was a Mark 5 aircraft available we drooped the flaps on the Mark 4 and flew both aircraft in competition to altitude. The modified Mark 4 out performed the Mark 5. We then drooped the flaps on the Mark 5 and it then outperformed the Mark 4 with drooped flaps. The absolute increase in performance was less for the drooped flap Mark 5 than for the drooped flap Mark 4. Needless to say the drooped flaps were never accepted by the RCAF. I suspect that it was down-played by management for reasons only known to themselves. To have incorporated this feature, flaps only, would have required a simple change in the hydraulic and flap angle sensing equipment. The weight penalty would have been less than ten pounds at a cost of a few hundred dollars per aircraft.

4) Vortex Generators

What is a vortex generator?

Flight Test Experiences involving Peter Cope

At this point I will describe some of the incidences wherein the specific pilots were involved. Although the pilots were assigned to specific types of testing, e.g. armament, performance etc., they often filled in for one another depending on their work load and availability.

Peter Cope was assigned by Don Rogers, the Chief Test Pilot, to conduct armament related testing. These included gun and rocket firing, Rocket Assisted take-offs and bomb release. There still was some overlap between he and Zurakowski as the work loads varied. Early in the CF-100 development program we concentrated on flight performance, stability and structural testing and as these types of tests were completed we moved on to armament and system testing as well as repeating performance tests as the CF-100s were modified such as the Mark IV and V. More on this later.

Rocket Assisted Take-offs (sometimes called JATO were J stands for jet assist which is a misnomer)

In order to provide the CF-100 with the ability to take-off from short runways at maximum take-off weight, the engineering office designed a rig containing six rocket motors to interface with the CF-100 structure. The rig and the six rocket motors were attached to the bottom of the fuselage immediately aft of the landing flaps. The rockets were tilted nozzle downwards so that their line of thrust would pass through the center of gravity (c.g.) of the airplane to eliminate the trim changes during the firing period of the rockets. Peter and I went to Ottawa to conduct the tests as we were nearer to the RCAF Base to take advantage of their logistics for handling explosives. This exercise went without a hitch, a credit to the designers, especially John Archibald (an unsung hero) for such a successful operation. These tests cleared the CF-100 for such an operation if needed in the future. To my knowledge the RCAF were never called upon to use this device.

Gun Firing

As part of its armament, the CF-100 Mark 3 and 4 versions were equipped with a detachable gun pack which was mounted on the under-side of the fuselage immediately aft of the nose landing gear well. The pack was self contained and comprised eight Colt Browning 0.5 inch calibre machine guns along with 200 rounds per gun, for a total of 1600 rounds. The feature of the self contained pack was that the reloading, and thus turn-around time would be quite brief.

The firing trials did provide a few surprises, such as when Peter Cope returned from a "shoot" with a spent bullet in the nacelle which was attributed to using old ammunition and during firing the lower velocity shell collided with a higher velocity round and deflected into the nacelle and damaged the Orenda engine.

One problem that must be addressed is the matter of gun gas build-up that occurs during firing. The designer does his best to provide adequate ventilation but the problem is too complex to solve without actually measuring the gas/air content during actual airborn firing tests. What may happen is that pockets of gas build up in areas where there is poor or inadequate air flow and a spark or flame from the gun breech may ignited the volatile gas mixture. So a particular series of firings were allocated to measuring the gases produced by the gun firing to determine the lower and upper explosive limits. We wanted to establish that the ventilation of the gun pack would always maintain the explosive mixture below the lower limit. Engineering project leader for this program was George-OSCAR------and he had arranged for the support of one of the local testing laboratories to supply us with a series of evacuated bottles which were installed in the gun bay. The objective was to release the bottle stopper during the firing which would then suck in a sample of the gas mixture. Upon landing the bottles would be delivered to the laboratory for analysis. This was a most laborious, time consuming and very costly process and I had estimated that we would require up to 50 flights to cover the designated flight regime. In addition that if indeed the gas mixture were to exceed the Lower Explosive Limit (L.E.L.) during the firing of the guns there was a high probability that an actual explosion might occur and lead to a disaster. As I didn't have much luck with engineering in providing a better method of determining the L.E.L., Bill Barratt and I approached a firm in the USA who had developed a "sniffer sensor" that would instantaneously determine the ratio of explosive gas passing through its orifice. We immediately contracted to obtain a number of these sensors and with a maximum effort Bill Barratt and his instrumentation team interfaced the output of these sensors with the continuos trace oscillograph recorder that was installed in the CF-100. The graphs produced by the oscillograph contained a complete survey of the gases throughout the firing and at the same time correlate these data with the aircraft flight such as speed, altitude, "g", engine thrust etc. As a final touch Bill rigged up a small simple display for the pilot, Peter Cope which presented the actual gas mixture percentage during firing along with a light to alert Peter when and if the mixture was approaching the Lower Explosive Limit (L.E.L.). Even with this arrangement engineering were skeptical and we had to take along those wretched bottles to assure them, in this case George-OSCAR----, that the new instrumentation was valid. We achieved our objectives with less than 20 per cent of the flights had we continued on the original method. Not only did we establish that the probability of the gas mixture reaching the L.E.L., we did save great deal of flying hours (about $1000 per hour in those days), a lot of ammunition and worn out gun barrels and of most importance at a much reduced risk.

Wing Tip Rocket Pods.

The CF-100 was equipped with two rocket pods, one on each wing tip. Each pod contained twenty-nine (29) 2.75 inch diameter Folding Fin Air rockets. These rockets contained no guidance and relied solely on the aiming data presented to the pilot by the Hughes APG-40 radar fire control system.

Prior to the flight tests we had fabricated several scale models of the streamlined (ready to fire), and unstreamlined (all rockets fired) pods. We took great pains to make sure that these models were not only representing the aerodynamic shape of the pods, but that the mass and inertia were also correct. This took some doing and it was through the skill of our instrumentation craftsman, Eric Wolfenden who managed to duplicate both nose and tail cones which could not exceed a thousandth of an inch in thickness in order to achieve the appropriate mass properties. Eric machined mandrels to the scaled rocket pod shape and then mastered a technique of filament winding using fine fiber-glass threads and expoxy. It was a first class job. We delivered these models to engineering who conducted jettison tests in the wind tunnel at Ottawa. For both loaded and fired conditions the trajectory of the jettisoned pods were photographed with cine cameras and posed no danger of impacting the CF-100 tail assembly. We had supplied a number of the models since once they were jettisoned, they were destroyed as they were very fragile. We were pleased that during flight trials in which the pods were jettisoned and photographed from the accompanying JetLiner the trajectory path was precisely as had been demonstrated in the wind tunnel.

The actual flight firing tests were relatively uneventful; the only problems that occurred were mainly due to the unpredictability of the rockets themselves. In a few cases an errant rocket might collide with another one and be thrown off course. Again the Avro Jetliner was a valuable asset for these trials, as we were able to use the Jetliner as an observation base and photographic platform for both still and high speed movie cameras to capture these events.

Jan Zurakowski experiences on CF-100 No. 18112

Aircraft No. 18112 was selected to be used as a trial installation vehicle for the Mark IV production prototype systems. We had installed quite a sophisticated instrumentation system that could be adapted for a variety of tests. The first series of tests were to measure the performance, stability and handling of the structural changes that had been made to cure the wing/nacelle fairing problems. This was followed by the introduction of vortex generators and flap manipulation that, though unappreciated by management, substantially enhanced the performance of the CF-100 at high altitudes and Mach Numbers. This was followed by the achievement of supersonic flight in dives. The final series of tests were the trial installation of the activated belly pack containing 56 2.75 inch FFA rockets. During the flight testing of this installation the aircraft crashed killing the engineering flight test observer Bob Ostrander and injuring the pilot Jan Zurakowski who bailed out just in the nick of time prior to aircraft impact.

Enhanced Performance by means of wing flaps and vortex generators

During performance tests, we for some reason or other decided to set the wing flaps at 5, 10 and 15 degrees in order to reduce the angle attack of the wing at high altitude to see if this reduction would have any effect on the performance of the CF-100 at the high altitudes and Mach Number especially with respect to "pulling g". We felt that if we could squeeze a few extra degrees prior to wing stall it might be possible to make tighter turns at the high altitude and Mach Number. At high altitudes the indicated airspeed is quite low, which requires a higher angle of attack. Lowering the flap effects the wing lift line in such a manner that, where for a given indicated airspeed the angle of attack is, say 6 degrees, to maintain lift for level flight, then adding 10 degrees of down flap reduces the need angle of attack of the wing by several degrees. This leaves more wing degrees available to achieve more lift as would be required to perform a tight turn prior reaching the critical angle of attack where wing buffet or stall occurs. On the negative side a penalty may have to be paid because of the drag increase caused by dropping the flap.
To our great surprise, the flight tests revealed a substantial gain in the available lift at altitude. The amount was

TO BE RE-WRITTEN