WINGTIP COUPLING AT 15,000 FEET

DANGEROUS EXPERIMENTS

BY C.E. "BUD" ANDERSON

Wingtip coupling evolved from an invention by Dr. Richard Vogt, a German scientist who emigrated to the U.S. after WW II. The basic concept involved increasing an aircraft's range by attaching two "free-floating," fuel-carrying aerodynamic panels to the wingtips. This could be accomplished without undue structural weight penalties as long as the panels were free to articulate and support themselves with their own aerodynamic lift. The panels would increase the basic wing configuration's aspect ratio and would therefore significantly reduce induced drag; the "free" extra fuel carried by this more efficient wing would considerably increase an aircraft's range.

Soon, other logical uses of this unusual concept became apparent: for example, two escort fighters might be carried along "free" on a large bomber without sacrificing its range. To be feasible, the wingtip extensions, or panels, whatever they were, would have to be kept properly aligned, preferably by a simple and automatic flight-control system.

But there was also the problem of how such fuel-carrying extensions could be handled on the ground. How would they be supported without airflow to hold them up?—perhaps by the use of a retractable outrigger landing gear, but what about runway width requirements? And—the big question—what about the stability and control problems that might be induced by such a configuration; would the extensions be easy to control? Many questions are also immedi-

The second wingtip-coupling experiment involved an ETB-29A and two EF-84Bs (photo courtesy of Peter M. Bowers).

ately apparent with regard to the viability of a bomber towing two fighters. How difficult would midair couplings be? Would there be stability and control problems? What about pilot fatigue, and would it be possible to develop an automatic system to control the coupled fighters?

Research revealed that Germany had conducted experiments in 1944 and 1945, but the tests and results had not been well-documented; it is known, however, that two light planes of equal size were flown in coupled flight. The aircraft were connected with a rope or cable through their wingtips; they took off side by side, and the rope had enough play to allow routine formation flying. Once at a safe altitude, one of

We completed 231 Q-14/C-47 couplings before the switch was made to the EF-84B/ETB-29A aircraft. Note the Q-14's skewed nose angle compared with the C-47's (photos courtesy of author).

Wingtip vortices and air turbulence initially made wingtip coupling quite tricky, but when I had practiced the procedure, they became less problematic. Seventeen pilots learned to couple the Culver Q-14 to the C-47.

the aircraft winched in the rope until the wingtip joints snapped into place—a connection like a universal joint. The aircraft were flown much as if in formation; they made some wide turns and changed altitude. An apparent lack of interest caused the German Air Ministry to drop the project, and it isn't clear why the experiments were ever conducted in the first place.

At Wright Field, Ohio, starting in the late 1940s, the concept was given new life through Dr. Vogt's proposals to the U.S. Air Force. A simple project—involving a C-47 and a Q-14—to investigate air-to-air coupling was tested at Wright Field to determine the concept's feasibility.

Meanwhile, a full-scale program was developed around a B-29 towing two F-84D straight-wing fighters. Republic Aviation Corp. was awarded a contract to design, build and evaluate this unusual combination.

This rather complex project involved a mechanical automatic control system, wingtip seals and flight-test instrumentation that would provide the data necessary to prove the concept quantitatively. At this point, I'll mention Ben Hohmann, another German who also worked at Wright Field after WW II. He was a down-to-earth, practical engineer who was able to make projects work. His experience, knowledge and ideas were used on many of the coupling mechanism's mechanical features. Further, he was a skilled pilot and flew as a C-47 crew member on many experimental test flights. He made great contributions to proving both the feasibility of the concept and to full-scale coupling projects.

The C-47/Q-14 experiments

In 1949, work began on the modification of a Douglas C-47A cargo aircraft and a small Q-14B target plane similar to the general-aviation Culver Cadet. These aircraft were chosen because they had approximately the same mass and span ratio as the full-scale B-29/F-84 project planes. This was to be a simple, quick, low-cost test to get some answers about the feasibility of air-to-air couplings.

In the interest of simplicity, the coupling device was a single joint attachment that permitted three degrees of freedom for the Q-14. A small ring was placed on a short boom attached to the C-47's right wingtip, and only local reinforcement was necessary, since the Q-14 would be supported by its own aerodynamic lift. A lance was mounted on the Q-14's left wingtip, and by pointing this rearward, the designers avoided the need for a locking mechanism because drag would keep the aircraft in place. Of course, this added a minor complication that required the Q-14 to "back" into the ring, which was a little unnatural. To uncouple, the Q-14's pilot would advance the throttle and fly forward out of the ring; and the C-47 was equipped with an emergency mechanism that would immediately release the ring from the wingtip boom for instant separation.

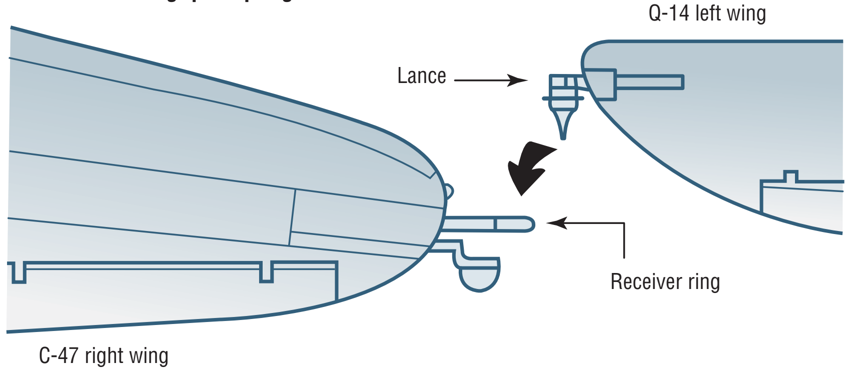
The initial attempt to couple was made on August 19, 1949, at Wright Field, Ohio, and it proved to be interesting. There was considerable apprehension about how stable the Q-14 would be if coupling were accomplished. Once coupled, it was hoped that the planes' positions would be maintained by using the ailerons, but some doubted this and reasoned that the elevator might be a better primary control. Because this was an inexpensive and quick feasibility test, they hadn't done any wind-tunnel or computer studies; in fact, because no one could accurately predict the outcome, we were all ready for anything.

Preliminary flights close to the C-47 tip with the coupling mechanism installed revealed a strong vortex airflow about the wingtip that made precise close-formation flight quite difficult. For safety, during the first attempt, the C-47 climbed to 8,000 feet—an altitude at which the Q-14 had little or no excess power for maneuvering into or out of position, and this proved to be a problem. At this time, the engagement ring was three inches from the wingtip.

This test run was unexpectedly difficult because of the strong wingtip vortex airflow and the unavailability of reserve power to maneuver the lance backwards into the ring. It was like trying to thread a needle into the middle of a fire hose. Our uncertainty about what might happen once the coupling had been accomplished also could have played its part. After about 30 minutes of attempting to make a smooth, subtle engagement, I decided that the only way to couple was to line up as closely as I could and then to reduce power faster than was really desirable. This worked, and on contact, the Q-14 immediately dropped to a 90-degree, nose-down position in relation to the C-47's wingtip. This didn't seem right to me, so I advanced the power to bring about an immediate disengagement. The whole thing happened in a few seconds. We didn't try again that day because we saw that the C-47's wingtip was slightly bent.

After talking it over, we recommended several modifications: to reduce the effect of the wingtip vortex, we asked that the engagement ring be moved about 19 inches outward on the wingtip boom. Further, we felt that the ailerons were ineffective and that we could have made a smooth engagement by keeping the power up until we discovered how to control the Q-14 near the engagement point.

C-47A/Q-14 wingtip coupling



On October 7, 1949, we tried again, and after considerable maneuvering, we were successful. This time, we reduced power only partially, and it was found that the elevator was a primary control. At first, we found it difficult to adjust to using the elevator for roll control because our automatic reaction was to use ailerons for roll about the coupled point. We made four couplings on that day, the longest coupled flight lasting five minutes.

After that, as we gained experience, coupled flight seemed quite easy—almost routine. We found that the best technique was to make the hook-up at the lowest altitude where the air was smooth. The C-47 stabilized at 95 knots to give the Q-14 enough reserve power to maneuver into and out of position; and as coupling became routine for us, our average time to hook up was reduced to between 10 and 30 seconds. Once hooked up, we reduced the Q-14's power to idle and controlled it exclusively with the elevator. The ailerons were almost completely ineffective, and we could easily override full aileron with a very slight elevator movement. Once coupled, the C-47 could increase airspeed to a normal cruise of around 120 knots, at which point coupled stability actually improved. At that speed, the coupled C-47 could do about anything that was normal—roll, climb and dive in smooth air, turbulence, or bad weather. Even night couplings became part of the test program. In the Q-14, hands-off flying was never possible for more than a few seconds. Since the Q-14 was basically a remotely controlled target aircraft, it had an autopilot system. Attempts were made to tie in autopilot elevator control with a flap-angle-limiting microswitch sensor, but this was largely unsuccessful and beyond the program's original scope. To see whether the single outboard aileron would control flap angle more effectively, we even disconnected the inboard aileron because it worked against us. Roll rate improved slightly when we used the single aileron, but control was still inadequate. To prove the point, we had the engagement ring on the C-47 wingtip moved back to the original three-inch position, and we then made successful couplings under the influence of the stronger wingtip vortex. Once the Q-14 pilot had gained complete confidence, he could maintain position by flying on instruments, if he wanted to. He only had to watch the turn/bank indicator and keep the ball centered with the elevator.

Up to October 1950, though performance data wasn't gathered, our accomplishments were:

- 231 wingtip couplings.
- 28:35 total coupled flight hours.
- 17 pilots familiarized with technique.
- 56 night couplings (2:09 hours total).
- Longest coupled flight: 4:08 hours.
- Proved feasibility of coupled flight.
- Showed that smooth air was required to couple.
- Demonstrated that pilots could be trained.
- Elevator shown to be primary control (ailerons ineffective).

Many pilots—most of them fighter pilots—were involved with the coupling experiments, and some were more used to multi-engine aircraft. Only one failed to make a midair coupling, but night coupling and bad-weather flying weren't problems. We were confident that couplings were possible under controlled experimental conditions, but we still had many questions—technical and operational—and we needed answers. Moreover, the nature of these tests was such that we didn't obtain any performance data that would validate the concept to the aeronautics community.

Later, as more pilots were checked out, they completed further—undocumented—couplings, and the C-47/Q-14 combination was later used as a warm-up for the full-scale B 29/F-84 test program.

B-29/F-84 wingtip towing

In the summer of 1950, the hardware for the full-scale B-29/F-84 experiments (Project MX1016) was ready to be flight-tested by contract with Republic Aviation Corp., Long Island, New York. The project called for the modification of a standard, four-engine, propeller-driven B-29A bomber to permit the in-flight towing of two straight-wing F-84D jet fighters. The test program was planned to demonstrate the full-scale feasibility of this concept and to collect data to prove the drag-reducing benefits of wingtip towing.

The B-29 was modified by having its outer wing panels replaced with new ones that were equipped with a wingtip towing/retrieving mechanism. In general, this consisted of a

Lift distribution in coupled flight

hydraulically actuated cylinder that could be extended outward about 18 inches from the wingtip. A receiver, internally shaped to match the F-84 lance, was mounted on the end of the cylinder; it was also attached to a fork to allow it limited movement about all three axes when extended. A hydraulic "snubber" attached to the inboard end of the retrieving cylinder would absorb the energy imposed by the fighter's forward movement during initial engagement. Rubber pads were installed at each B-29 wingtip to form a seal that was important for aerodynamic performance.

The modification to the two F-84 fighters was relatively simple: a forward-facing lance that was used to engage the B-29 receiver was installed. The lance's oblong tip rotated through 90 degrees to form a lock when fully inserted. A hydromechanical connection joined the lance shaft and the F-84 aileron control. It was hoped that this simple method, which was based on a ratio of lance rotation or flap angle to aileron movement, would provide automatic control.

The system could be manually overridden by the F-84 pilot or could easily be disconnected if required. The results of the C-47/Q-14 tests led to doubts that the ailerons would be able to provide the necessary control power. The F-84 was free in pitch, roll and yaw about the coupling point at the wingtip.

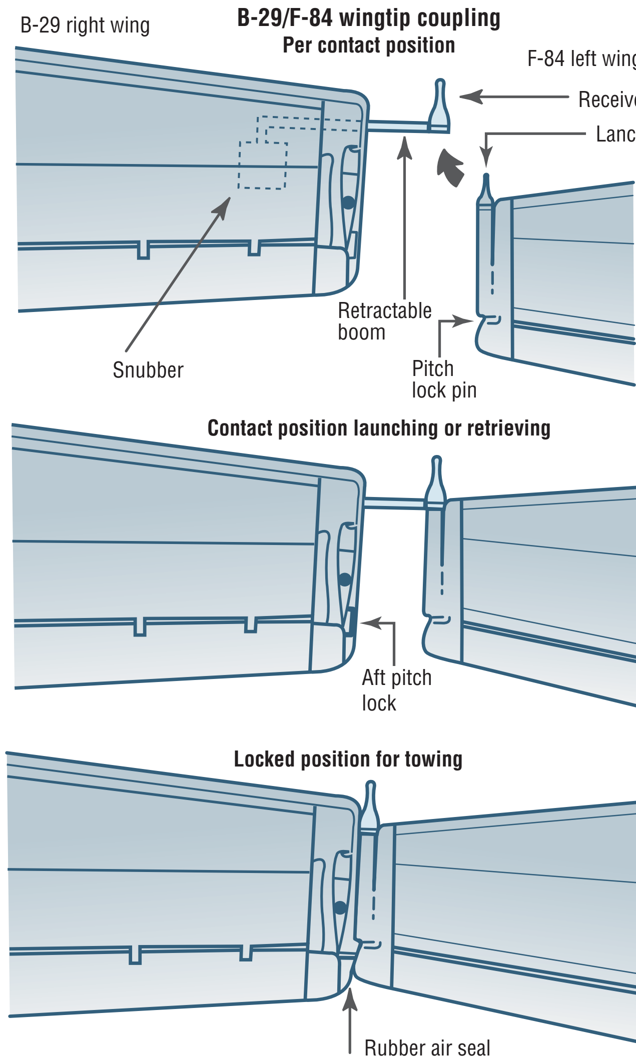
For towing, the retrieving cylinder was retracted inboard to the locked position. The aft locking mechanism matched up with the F-84's aft wingtip area, and an arm moved out from the B-29 over a pin in the F-84. At this point, the hydraulic snubber wasn't necessary because the F-84 was now fixed in pitch and yaw, and this allowed only a flapping action or a roll about the longitudinal axis between the wingtips. An emergency-release system of explosive bolts was installed; it could be activated manually from either aircraft or automatically, if preset flapping-angle limits were exceeded.

The B-29 and the right-hand F-84 were fully instrumented for development investigation and to collect performance data. The left-hand F-84 had all the modifications but no data instrumentation.

Test results

July 21, 1950, Long Island, New York. The first attempt to couple the B-29 and F-84s was successful: the right-hand F-84 made four successful engagements, including one full retrieve-and-launch cycle. The lance/aileron connection had been disconnected, and the B-29 aft lock had been replaced with a flat plate to check the match-up with the F-84.

We discovered that this was a much more delicate operation than the C-47/Q-14 combination: air circulation around the wingtip still presented a problem. The lag in jet-engine thrust response also added a new obstacle to a precise wingtip coupling. A smooth, steady lineup and insertion of the lance produced satisfactory hook-ups. If the receiver was engaged with a sharp, solid, contact, however, a lateral structural oscillation would be induced along the B-29 wing. If this was not stopped immediately or if corrective action got out of phase, the oscillation increased and the F-84 had to be released immediately. This raised our concerns about the possibility of flying in any kind of rough air. The C-47 was very rigid, and we didn't notice any structural oscillations, even in turbulence. The B-29 wing, on the other hand, was quite flexible, and at times, keeping things under control was rather nerve-racking. It also increased our determination to make a precise engagement, and consequently, we never intentionally flew in rough air.



We had no problems controlling the F-84 while it was engaged in the receiver at the extended position. But it was free to roll, pitch and yaw about the contact point, and any quick control movements could set up this structural oscillation, so I always felt better once the retrieving cylinder had been retracted and locked for towing. Having retracted it, I would reduce power to idle or to engine cut-off. The aft lock held the F-84 firmly in yaw, and the only motion would be an up or down flapping as the F-84 rolled about the longitudinal attachment line between the wingtips. I soon found that aileron control was not sufficient to maintain the desired position. The elevator was, of course, very effective, but now, since the wingtips were locked in pitch, I maintained the proper attitude by twisting the B-29 wing structure to some degree.

When I activated and checked the mechanical hydraulic aileron/lance connection system, I soon found it was inadequate, and it was soon deactivated for the rest of the program. Before the flapping limits had been properly adjusted, we had a few emergency disconnects, and we had some difficulty with the lance receiver engagements because of close-fit tolerance and bent locking tips. The receiver also tended to turn when bumped, and it would not re-center itself properly. The tolerances were enlarged with a file, and spring snubbers were added to keep the receivers centered.

In the left-hand F-84, pilot Maj. John M. Davis started to attempt engagement on flight three. Many successful attempts followed, but the mechanical problems mentioned delayed full-scale flight with both F-84s in the locked position until September 15, 1950—flight 10. Two complete cycles of dual-towed flight time totaled about 30 minutes.

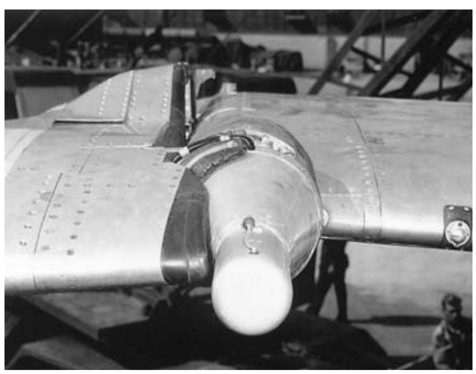
We accomplished towed flight with the F-84 engines in idle power as well as shut down. The F-84 engine continued to windmill when shut down because there was no way for us to cut off the airflow through the air inlet. We didn't have problems with F-84 engine air starts, and we flew shallow banks with the two fighters hooked up, but at the boom-extended position. We quickly learned that we didn't like that, because in the extended position, both fighters were free in pitch, roll and yaw, and any upsetting motion would start both fighters oscillating about the hook-up point. We found that the best procedure was to get hooked up and into the retracted and locked position as soon as we could.

During flight 11, we tried the single-aileron idea. We intended to disable the inboard aileron, which provided adverse roll control about the coupled axis. We disconnected the inboard aileron, hoping that the outboard aileron would provide enough rolling power to control the flapping angle. Single-aileron engagements were more difficult, but we successfully completed several such towed flights.

As we had discovered previously in the Q-14 experiments, single-aileron operation improved roll control, but it still wasn't enough to maintain the proper flapping angles while we were maneuvering. The elevators were the primary controls, but with the F-84/B-29 combination, this was done by twisting the B-29's wing structure. We measured loads on the outer wing panels, and they weren't excessive.

Flight 12—October 19, 1950. We wanted to obtain performance data during dual-towed flight, and both fighters were locked in tow for approximately 1 hour, 40 minutes. We banked left and right at 10 degrees, and calibrated speed and power at 20,000, 15,000 and 10,000 feet; during these tests, we varied our airspeed from 195 to 156 knots. The fighters were always coupled, even during the letdown to the lower altitudes. Unfortunately, the data recorder failed, so the next day, we repeated the flight; this lasted approximately 2 hours, 40 minutes—the longest dual-towed flight. The performance data profile was repeated, and we recorded data.

That flight was the last in the documented part of the program; Republic Aviation Corp.'s published report clearly proved the induced-drag-reduction benefits of wingtip coupling.



Top: the left-hand EF-84B's right wing lance is in position to contact the ETB-29A's left wing receiver. Center: once contact had been made, the receiver retracted into the ETB-29A's wing and the planes were fully coupled. Above: fitted to the ETB-29A's wingtip was a rubber seal, so when the wingtips were in the retracted position, there was an airtight bond between them.

The accomplishments documented during the test-program contract showed 43 individual couplings by two pilots and 15 hours of towed flight—counting both single and dual tows. The longest dual-towed flight lasted more than two hours, and towing seemed to be feasible in smooth air. We validated the concept with quantitative data that proved that a bomber could tow two fighters on its wingtips with only a very small reduction in its range.

From the performance data gathered during the two, long, dual-towed flights, we generated a drag polar curve and showed that at the higher gross weight and lower airspeeds, the B-29/F-84 combination was more efficient than the B-29 alone; however, at low gross weight and high airspeed, the B-29 alone displayed the best performance characteristics. The study certainly validated the floating-panel concept.

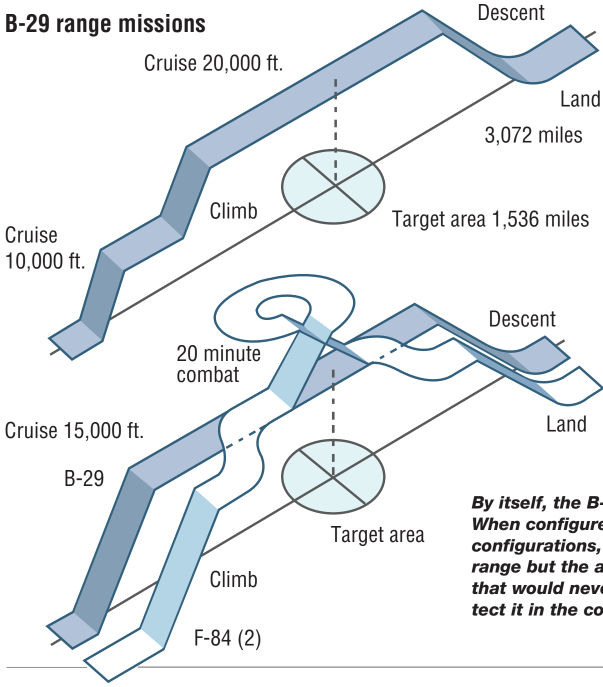
From the drag and performance data collected, mission ranges were calculated to allow a comparison of typical B-29 missions with towed ones. The basic single B-29 mission was regarded as a baseline. When it carried the two F-84s on an identical profile, the result was a range loss of only 7½ percent. If, however, the profile was optimized for the aerodynamic configuration of dual towing by cruising at a lower altitude, only a 2.9 percent range loss was experienced. Theoretical studies actually predicted a very slight increase in B-29 range, and if the air seals between the wingtips had been refined, this might have been proved to be true.

System improvement

When Republic Aviation Corp. had completed its initial contract, it was further contracted to update the configuration and to incorporate a more sophisticated, automatic flight-control system. While the new system was in the design phase, the three aircraft remained at Wright Field, where we flew additional (undocumented) flights: for example, we demonstrated the viability of night engagements.

In the early part of 1953, the flight-test program was reactivated. The two fighters were modified to have mechanisms that closed the air inlet to the engines to reduce windmilling drag, and an adjustable rear latch was added to eliminate the wing twist.

The major change was the installation, in all three aircraft, of an automatic, electronic flight-control system. The B-29A carried a master control box that was to provide the central reference point. Each fighter's position was monitored through sensing devices, and if one was out of position, an electronic signal was sent out to its automatic flight-control system, and that commanded control



Configuration	Percent loss	Statute miles
Basic B-29-cruise at 10,000 and 20,000 (3,072 statute miles)	N/A	N/A
B-29 towing 2 F-84's, same profile as basic mission	-7.5	-230
B-29 towing 2 F-84's, hook up 5,000 cruise 15,000 and 20,000	-7.62	-234
B-29 towing 2 F-84's, hook up 5,000 cruise 20,000	-4.50	-138
B-29 towing 2 F-84's, hook up 15,000 cruise 20,000 (800 gallon fuel F-84s)	-4.55	-140
B-29 towing 2 F-84's, optimized for coupled flight	-2.90	-89

By itself, the B-29 had a range of 3,072 miles. When configured in one of the five listed towing configurations, the B-29 had a small loss of range but the added advantage of two fighters—that would never be able to fly that far—to protect it in the combat/target area.

movements that would re-establish the proper flapping angle. The biggest part of the program was devoted to the development of the automatic flight-control system, establishing the required damping frequencies and setting up the proper autopilot settings.

I always doubted that this could ever be accomplished. I had participated in certain basic autopilot development flight tests; one of the accepted test procedures was to set up the desired flight conditions, turn on the autopilot and then induce about a 1G pitch pulse and let go while measuring the system's damping capability. The test was repeated with many different damping ratios set into the autopilot until the system had been refined. During the design phase, an autopilot engineer confirmed my worst fears: this technique would be required to develop, check out and set up the B-29 wingtip-towing automatic-flight-control system. I could not envision ever making a pitch pulse of any magnitude while coupled in towed flight, nor could I imagine letting go of the control stick if there were any flapping action at all. The F-84 elevator's tremendous power was very apparent to both pilots; pitch control was treated with great respect and with full anticipation of the consequences of mishandling it.

By this time, I had been transferred to desk duty at the Pentagon, so I lost interest until I was called to help out on the preliminary checkout flights at Farmingdale, Long Island. The right-hand F-84 was the fully instrumented fighter so, during initial checks, they had generally obtained data from that one. As I recall, they flew six flights during March and April 1953; we checked out the new systems individually and managed single coupled and towed flights. Electrical power from the B-29 could never be received in the right-side F-84, but it had been consistently available in the non-instrumented, left-side F-84. Both F-84 autopilots had been up identically for the initial flight-control-system test. For this reason, we agreed that on the next flight, if the right side F-84 didn't have electric power, the automatic flight-control system would be activated momentarily using power from the other one.

April 24, 1953—the next test flight. We coupled and flew a fully towed flight using the right-side F-84, but again, there wasn't any electrical power from the B-29. The right-side F-84 was uncoupled, and the left fighter, again piloted by Maj. Davis, was coupled with the B-29 and then retracted in the fully locked towing position. The cockpit-panel light indicated that electrical power was available from the B-29, so as soon as we had trimmed and stabilized everything, the automatic flight-control system was activated momentarily from the fighter. This action resulted in the F-84's pitching violently and then flapping upward and into the B-29. The B-29's outer wing panel crumpled as the F-84 rolled into it and, when inverted, struck the B-29's main wing spar; before the two aircraft separated, this impact sheared off the F-84's nose section forward of the cockpit. The B-29 then went into a steep spiral and crashed into Peconic Bay, Long Island, and the F-84 went down shortly afterward. No one survived.

This disaster put a large damper on the entire concept, but two more major projects were completed before interest was totally lost. During 1952 and 1953, a project was conducted under contract by the General Dynamics Corp., Convair Division at Fort Worth, Texas. Code-named "Tom-Tom," it involved the wingtip coupling of the RB-36F with two sweptwing RF-84F fighters. Then, during 1955 and 1956, Beechcraft was contracted to build, install and test a set of small, fuel-carrying, wingtip floating-panel extensions on a military Beech L-23. Code-named "Long Tom," the project was successfully completed, and it demonstrated a significant improvement in range.

In summary, the floating-wing-panel concept was shown to be valid, but there are still technical problems, particularly in the areas of stability and control, structural dynamics and automatic flight. Since the B-29/F-84 tests were conducted, these problems may have been compounded by other technological advances such as supersonic flight. Today, the practical use of the fighter-towing concept appears to be somewhat vague, but Dr. Vogt's aerodynamic invention that provided "something for nothing" is still available. Perhaps today's high fuel costs make its range-extension application more pertinent than ever. I recall that the first in-flight refueling experiments were done in the 1920s, but the technique wasn't applied widely until the Strategic Air Command adopted in-flight refueling as a routine, day-to-day operation in the 1950s. ✢

Editors' note: check out Bud Anderson's website at: www.cebudanderson.com.