AIAA Journal
Vol. 43, No. 4, April 2005

The Supercritical Peanut: The Navy's Pioneer in High-Speed Flight Research

G. R. Inger
Iowa State University, Ames, Iowa 50011

Prologue

On 7 May 1940—a year and a half before Pearl Harbor—test pilot Woodward Burke climbed into a specially instrumented Brewster XF2A-2 experimental Navy fighter (Fig. 1), took off from Langley Field at 6 a.m. and headed for a remote area of the Chesapeake Bay on the Virginia peninsula. He was about to carry out the most dangerous of a series of high-speed test dives that had been under way during the previous week. These dives, carefully engineered and planned during the previous two years by the NACA Flight Loads group, working with the U.S. Navy Bureau of Aeronautics, were part of the world's first scientific in-flight investigation of supercritical flow around an airplane wing.

Reaching an altitude of 30,000 ft, Burke made a final check of the cockpit gauges, switched on the special instrumentation circuits with their automatic data recording devices, and then nosed the chunky Brewster (unofficially dubbed "The Peanut Special" by Navy pilots) down into a terminal-velocity dive designed to produce during the ensuing $11g$, 575-mph pullout a supercritical flight condition involving a pocket of supersonic flow on the specially instrumented inboard section of the wing.

Watching the dive through binoculars were two NACA aerodynamicists, John Stack and John Becker, who had driven out to Grandview as concerned observers; as Becker later wrote[1]: "We were most apprehensive as we watched the dive through binoculars. This was before the possible effects of compressibility (significant flow density variations) on the buffeting and control of diving airplanes had been highlighted by the P-38 tragedy of 1941; nevertheless, our knowledge of shock-stalled flows in the wind tunnel left little doubt about the dangers of this dive. Happily, the flight was completed successfully without any undue difficulties. . . ."

Although the results of these dive tests and the related transonic wind tunnel corroboration had been an important milestone in high-speed aerodynamics research, they were destined to be unsung. The only documentation was in the form of an informal classified September 1940 memo of very limited distribution, appearing only later in an obscure mid-1943 NACA wartime report, by which time other, better known tests had overshadowed the achievement. The present paper seeks to redress this lack of recognition by giving for the first time a complete and fully documented account of why and how this pioneering and very successful research project was carried out. The account is based on a decade of in-depth research into NASA Langley (LaRC) and the U.S. Navy Bureau of Aeronautics (BurAer) records. In particular, frequent reference will be made to records held in the research authorization (RA) files at the Langley Historical Archives (LHA).

Project Origins

Series of Military High-Speed Dives

The attention of BurAer to the need for compressible aerodynamics research was provoked by a rapid series of events in 1939, beginning with the publicity attached to Lloyd Childs's 23 January high-speed dive of a Curtiss Hawk 75 demonstrator for a French purchasing commission.[2] Although the alleged maximum dive speed of 575 mph later proved to be exaggerated, it had attracted the attention of the aeronautical community to the occurrence of compressibility effects. This event was quickly followed by another well-publicized high-speed dive by U.S. Army Air Corps (USAAC) 2nd Lt. Troy Keith on 6 February: experiencing oxygen trouble flying his P-36 high above Barksdale Air Force Base, he entered a high-speed dive that attained an "estimated" 650 mph before pullout.[3] Two days later, on 8 February, Brewster itself fanned the flames of interest with a press release that claimed that speeds in excess of 500 mph were likely reached over a year earlier by test pilot Vance Breece during power dives of the XSBA-1 scout bomber prototype.[4]

Sharper Engineering Focus

These media-sensitive events were immediately brought into a sharper engineering focus by a 7 April 1939 high-speed dive demonstration of a biplane Curtiss SBC-4 "Helldiver" (BurAer Serial 1268), which resulted in noticeable damage to the metal upper wing skin. In its report on the incident to BurAer, Curtiss had ascribed the damage to possible compressibility effects associated with the 430-mph and $12.6g$ pullout conditions reached. While BurAer in turn referred the matter to NACA Langley for study[5] because of their long-standing interest in compressible flow research, it had also drawn the attention of BurAer's Chief of Structures, Cmdr. Lucien M. Grant. At Langley, the report had been handed over to the Chief of the Flight Loads Group, Richard Rhode, and his assistant, Henry Pearson. After careful study, they concluded in several memoranda back to Grant that the damage in this particular case, even

An aerospace engineering graduate of the University of Michigan, Professor George R. Inger has been a researcher, teacher, and consultant in the field of aerothermodynamics for over 40 years. He occupied the Glenn Murphy Chair of Engineering at Iowa State University from 1985 to 1989. Previously he had been Associate Chairman of Mechanical and Aerospace Engineering at West Virginia University following a 2-year stint as Chairman of Aerospace Engineering Sciences at the University of Colorado. From 1970 to 1980 he was a Professor at the Virginia Polytechnic Institute and State University, where he helped to develop a unique undergraduate and graduate combined aerospace/ocean engineering program and directed a number of research projects supported by NASA, the Office of Naval Research, the Air Force Office of Scientific Research, the National Science Foundation, and others. He has held industrial research positions at McDonnell Douglas, the Aerospace Corporation, Bell Aircraft, and the GM Research Laboratories. A former two-time Humboldt/Fulbright–Hays awardee, Inger is an Associate Fellow of the AIAA and a member of the American Aviation Historical Society.

Presented as Paper 2003-0288 at the 41st Aerospace Sciences Meeting, Reno, NV, 6–9 January 2003; received 9 September 2003; revision received 31 August 2004; accepted for publication 7 September 2004.

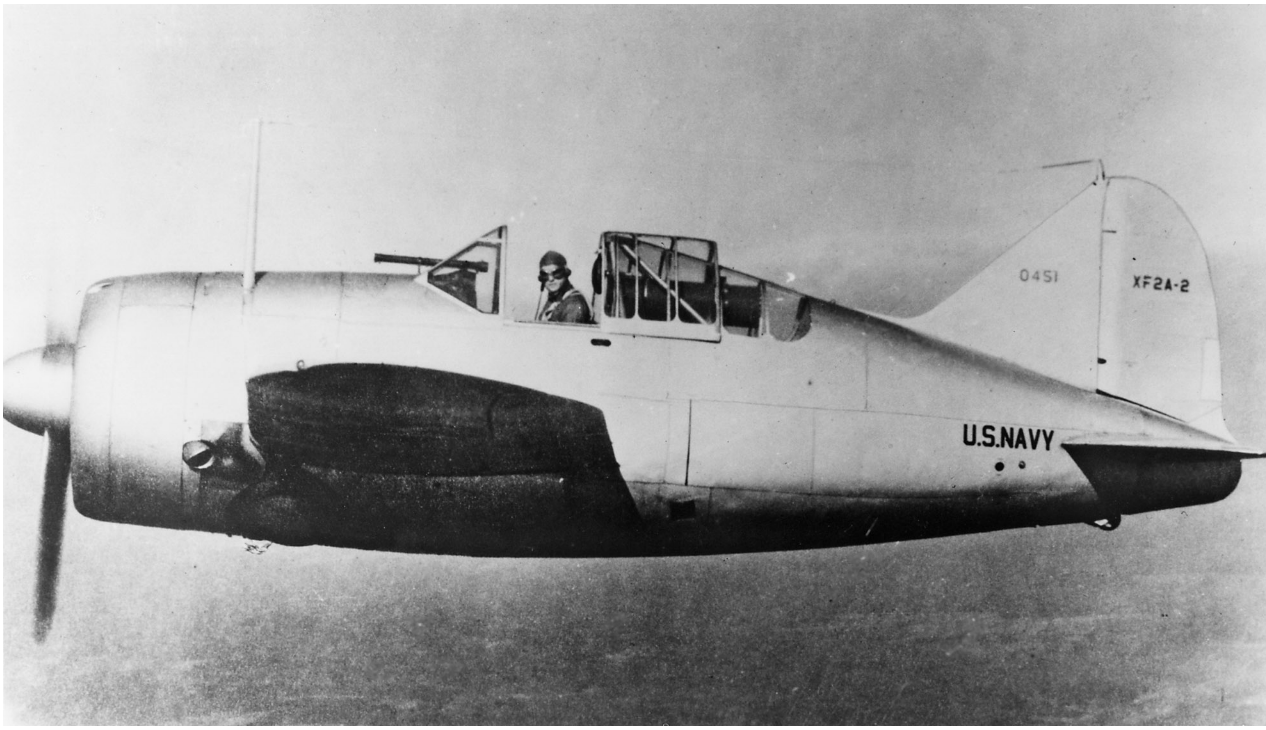


Fig. 1 Brewster XF2A-2 circa 1939, unofficially called "The Peanut Special" by USN personnel. (Specifications are given in Table 1.)

Table 1 Brewster XF2A-2 specifications[a]

Parameter	Value
Wingspan	35′
Length	25′7″
Height	12′
Gross weight	5942 lb.
Powerplant	One 1200-hp Wright R-1820-40 Cyclone air-cooled radial
Max. speed at 16,000′	344 mph
Service ceiling	34,000′

[a]The XF2A-2 was the prototype of an up-engined version of the Navy's first production carrier-based fighter, the F2A-1.

though compressibility effects were indeed present, were likely due to a change in wing loading distribution due to structural deformation. This finding might have dismissed the compressibility effect issue but for the timely occurrence of yet another high-speed dive episode in a P-36 in June: USAAC Lt. Moore had reached a maximum indicated speed of 550 mph with significant wing damage, and the matter had again been subsequently returned to Langley for study. As a result, it again fell to Rhode to assess the role of compressibility—and this time it was identified as the undoubted cause of spanwise rivet failure near the wing mid-chord. Rhode phoned Cmdr. Grant on 27 June about his findings: a pocket of local supersonic flow had formed on the wing, whose oscillating terminating shock wave (a sudden pressure jump) had caused the damage. Rhode followed this up 5 weeks later with a 4 August memo report[6] to Grant, "Compressibility Failure on the P-36 Airplane."

BurAer/NACA Team Is Formed

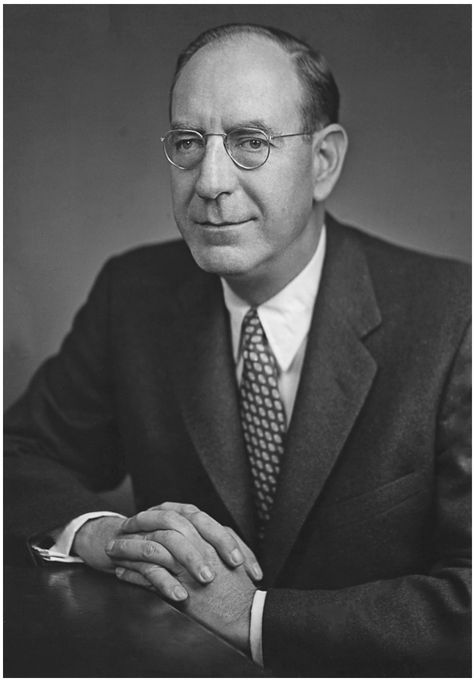
Stimulated by these events and the knowledge that BurAer had in the recently acquired Brewster XF2A-2 monoplane fighter a sturdy aircraft capable of very high speed dives (Fig. 1; Table 1), Cmdr. Grant became convinced that a serious controlled engineering flight test investigation of supercritical flow effects was both desirable and feasible. Thus it was that the Navy, rather than the Army Air Corps, seized upon the idea of such a project at so early a date (1939). Moving with energy, Grant (Fig. 2a) set into motion a series of events that were to culminate in a formal dive test program by the end of the year. Grant and his assistant R. L. Creel flew to Langley on 20 Sept. for a meeting with Rhode's group to discuss the feasibility of such tests.[7] Because Rhode (Fig. 2b) had been thinking along similar lines, the resulting meeting was productive; as Rhode later wrote: "I raised the question at the outset to determine whether it would be possible to arrange for such tests during routine contract dive demonstrations. It immediately developed that one of the principal questions that Commander Grant and Mr. Creel wished to bring up was whether our Laboratory saw the flight tests in the compressibility range as desirable and feasible. Apparently they had felt the necessity of such tests for some time and were anxious to see something done along these lines if it was considered at all feasible to do so. We therefore found ourselves in agreement at the beginning of the conversation on the desirability of conducting certain flight tests." These discussions made clear that controlled high-speed dive tests were a way to obtain direct flight assessment of compressibility effects, while also providing data to validate transonic wind-tunnel test results.

With this mutual accord established, Langley's Chief of Compressible Aerodynamics, John Stack, was called into the meeting and expressed agreement with the project. He emphasized the important but often overlooked point that the critical Mach number is considerably reduced at the higher angles of attack involved in dive pullouts, whereas most contemporary considerations of compressibility were confined to effects near zero lift appropriate to level flight; consequently there had been a tendency in the industry to overlook the structural aspects of the lower critical Mach number that occurred during high-speed dive pullouts. Grant and Creel concurred and indicated that others in the Navy as well were strongly backing such tests. The meeting then closed with a brief discussion of the possible effects of flutter and, in a little-known but important step that had a significant impact on the subsequent success of the project, Cmdr. Grant expressed his intention of consulting Langley on the matter (which he did, as will be discussed).

Test Aircraft Is Selected

With the aforementioned preliminary planning established, BurAer moved rapidly and less than a month later had selected the experimental Brewster XF2A-2 prototype (BurAer SN 0451) as the candidate airplane and had initiated contractual arrangements with Brewster to carry out the appropriate modifications and added

a) Captain Lucian Grant, the father of the BurAer-sponsored engineering project on flight compressibility



b) Richard S. Rhode, Chief of the Flight Loads Div. at NACA Langley

Fig. 2 BurAer/NACA team is formed.

instrumentation (Figs. 3 and 4). Six days later on 19 October 1939, the NACA formally approved[8] Langley Research Authorization 705 for "Study of the Effects of the Compressibility Burble in Flight." Langley then followed this up with a 24 Oct. memo to its Washington, D.C., headquarters suggesting that the flight test data could also serve to validate their transonic wind-tunnel results; as Langley's Engineer in Charge, H. J. E. Reid, wrote[9]: "The results of these measurements are not expected to provide an academic check of wind tunnel results. The measurements will, however, show whether wind tunnel data as applied to the basic section of sufficient indication of what is likely to occur under actual conditions." It is interesting to note that these dive test plans were being coordinated with none other than a Captain Moore of the USAAC Materiel Division, the very officer (now promoted) who had done the earlier P-36 dive. The USAAC was thus involved as an interested observer—but the Navy was the driving force and sponsoring agency for the project.

By early November, XF2A-2 drawings were supplied by Brewster to Langley for detailed test equipment specifications. Meanwhile, BurAer had prepared detailed contractual specifications for Brewster, which clearly emphasized the 8–9*g* pullout requirements (this was not lost on prospective test pilot candidates, as will be seen later!). On 15 November a formal RFP ("wired" of course for Brewster) was issued, culminating a month later[10] in the award on 2 Dec. of BurAer Contract 70851 for modifying the XF2A-2 to Brewster. Thus by the end of 1939, the Navy NACA Supercritical Dive Test Project had completed its planning stage and was in full swing.

The Project Moves Forward

A Test Pilot Is Found

In January 1940, the XF2A-2 was flown from the Naval Aircraft Factory in Philadelphia to the Brewster facility at Newark, where engineers and technicians began the process of modifying the airplane and adding the appropriate instrumentation. Easily removed equipment that was not essential for the tests was taken out to provide space and compensate for the weight of the special recording instruments. At the same time, the Curtiss electric propeller was modified to have a feathering circuit so the airplane could be dived to maximum possible air speed without overspeeding the engine; the propeller cuffs were also removed to prevent them from interfering with the cowling at high-pitch prop settings.

While this work was going on, albeit at the slow pace so typical of Brewster, an unanticipated problem arose concerning the acquisition of a suitable test pilot for the contract dives. Apparently, the rather demanding specifications mentioned previously were scaring off prospective candidates. The NACA itself became concerned about this, for in a 4 January Langley memo, Reid wrote[11]: "We understand from a verbal report that, at least up to a week ago, pilots who had originally shown an interest in bidding on this job, had backed down after reading the specifications. It is specifically desired to learn why the pilots are hedging; perhaps the specs that the dives are to be conducted under NACA supervision at Langley, causes them to suspect, since the NACA pilots themselves are not doing the job, that there is some danger involved that does not appear on the surface. If this is the case, it may be possible to convince them that the only reason that the NACA pilots have not been asked to do this job is because it was considered unfair to them to undertake it without extra compensation which could not be legally given." Fortunately, the problem was ultimately resolved with Brewster's hiring of a contemporary test pilot, Woodward Burke (Fig. 5). "Woody" Burke was a highly regarded and conscientious, if somewhat devil-may-care, test pilot typical of the period, and he apparently was not daunted by the specifications as were other pilots.

Meanwhile, yet another problem has arisen: during preliminary flight trials of the now-stripped-down modified XF2A-2, large amounts of CO leakage into the cockpit area had occurred. This had been traced and the entry sites plugged at the expense of yet further schedule slippage past the mid-February project completion date originally set by NACA.

The Brewster Fighter Is Instrumented

As stated in Ref. 12, "the instrumentation was planned to permit the most accurate practicable determination of the Mach number, the critical speed, and the behavior of the compression shock, as well as to permit observation of several features of the behavior of the airplane with the occurrence of the shock." The instruments included an airspeed recorder connected to a swiveling

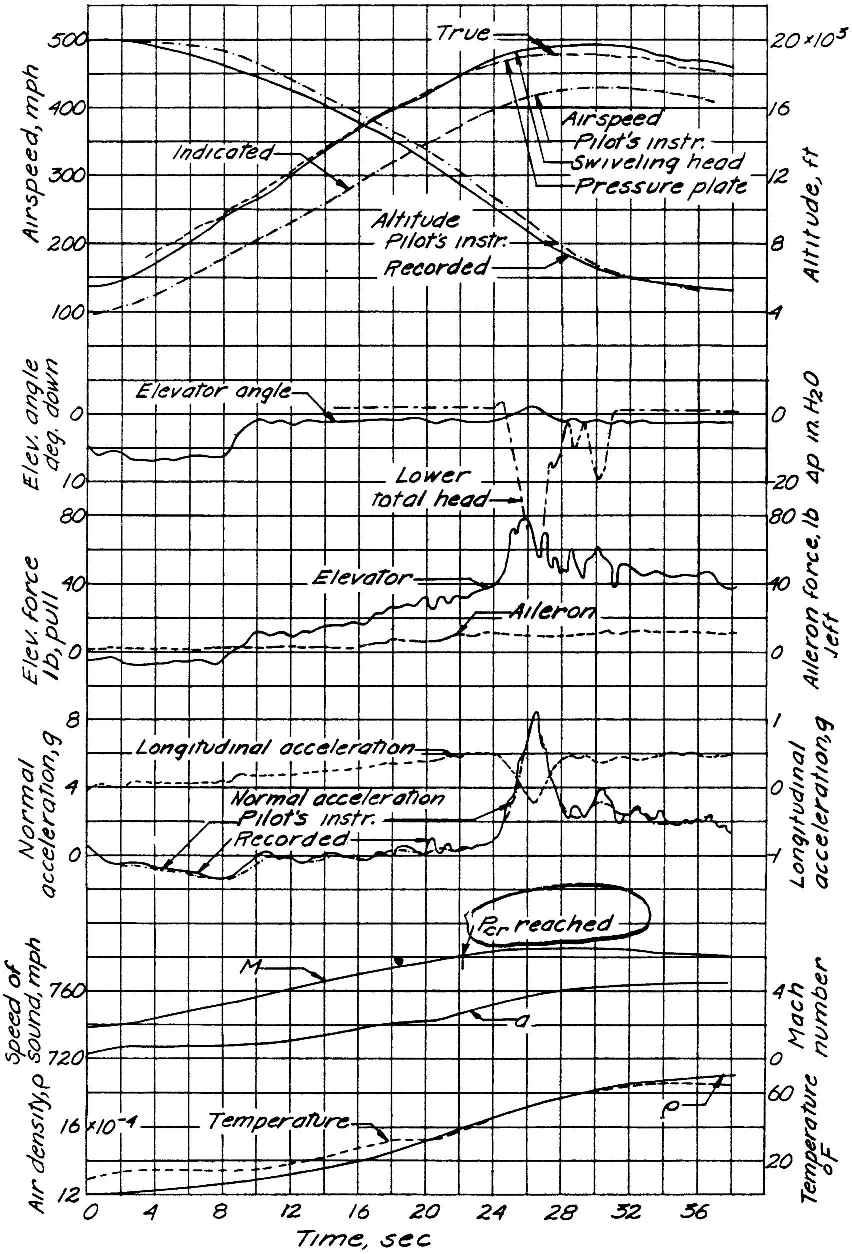


Fig. 3 Flight measurement records obtained during the 7 May 1940 supercritical dive.

pitot-static tube, a special "pressure-plate" airspeed recorder designed for high critical speed and elimination of time lag, a stem thermometer, 30- and 2-cell recording manometers, a sensitive altimeter, a two-component accelerometer, control-force and position recorders for elevator and ailerons, two 35-mm motion-picture cameras, a vibrograph/tachometer/timer set, and a velocity-acceleration (VG) recorder. These instruments were mounted as shown in Fig. 6. Especially noteworthy in the plan view is the chordwise row of static pressure orifices on a strip around the 40% span station of the right wing, which provided pressure distribution data along both upper and lower surfaces of the NACA 23014 airfoil section.

The installation of these items, however, had proceeded so slowly that NACA sent Hank Pearson down to Brewster to expedite matters in order to get flight tests carried out in the good weather off the coast of Virginia anticipated for the coming spring. The job was finally completed by March 1940 and the fully instrumented special XF2A-2 flown to the U.S. Navy (USN) Test Center at Anacostia for final check out. During the course of this, it was discovered that the weight of the modified airplane, including the pilot and parachute, had escalated to 5450 lb with shift of the CG 2-in. aft, which made the aircraft longitudinally unstable (not a desirable situation for an airplane about to undertake a series of very dangerous high-speed dive tests!) The problem was cured on the spot by relocating the tail hook assembly and shifting the instrument batteries slightly forward. Ready at long last, the modified Brewster fighter was ferried down to Langley on Thursday, 4 April 1940. Figure 6 shows a photo of this aircraft shortly after its arrival; in it can be seen the strip of static pressure orifices on the right wing plus special aerodynamic instrumentation aboard this strip.

Last-Minute Flutter Crisis

Langley was anxious to proceed, so the very next day its Chief of Flight Test, William McAvoy, took the Brewster out for a 35-min flight and pronounced it ready to go. But at this point yet another problem arose in connection with the control surface balancing to accommodate anticipated compressibility effects on the flutter characteristics. Cmdr. Grant had in the interim contacted Langley's Chief Physicist and flutter expert, Theodore Theodorson, about the problem; he had also asked Brewster to send data pertinent to flutter estimation. On 17 April, Theodorson (Fig. 7) received the needed information in a letter from Brewster's Chief of Structures, Earl

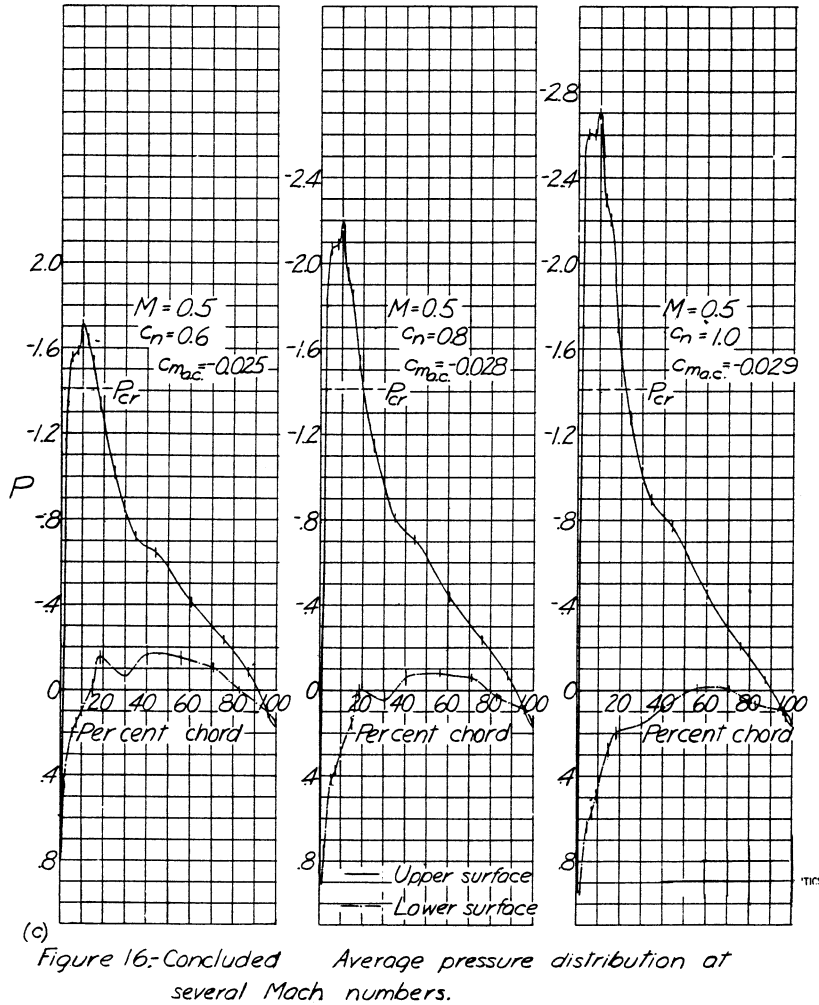


Fig. 4 Flight test wing section pressure distributions showing the occurrence of a supersonic region on the upper surface.

Fig. 5 Woodward ("Woody") Burke, the Brewster test pilot for the crucial instrumented dive series. Burke later became chief test pilot at McDonnell Aircraft and was killed testing the XFH-1 carrier jet in 1946.

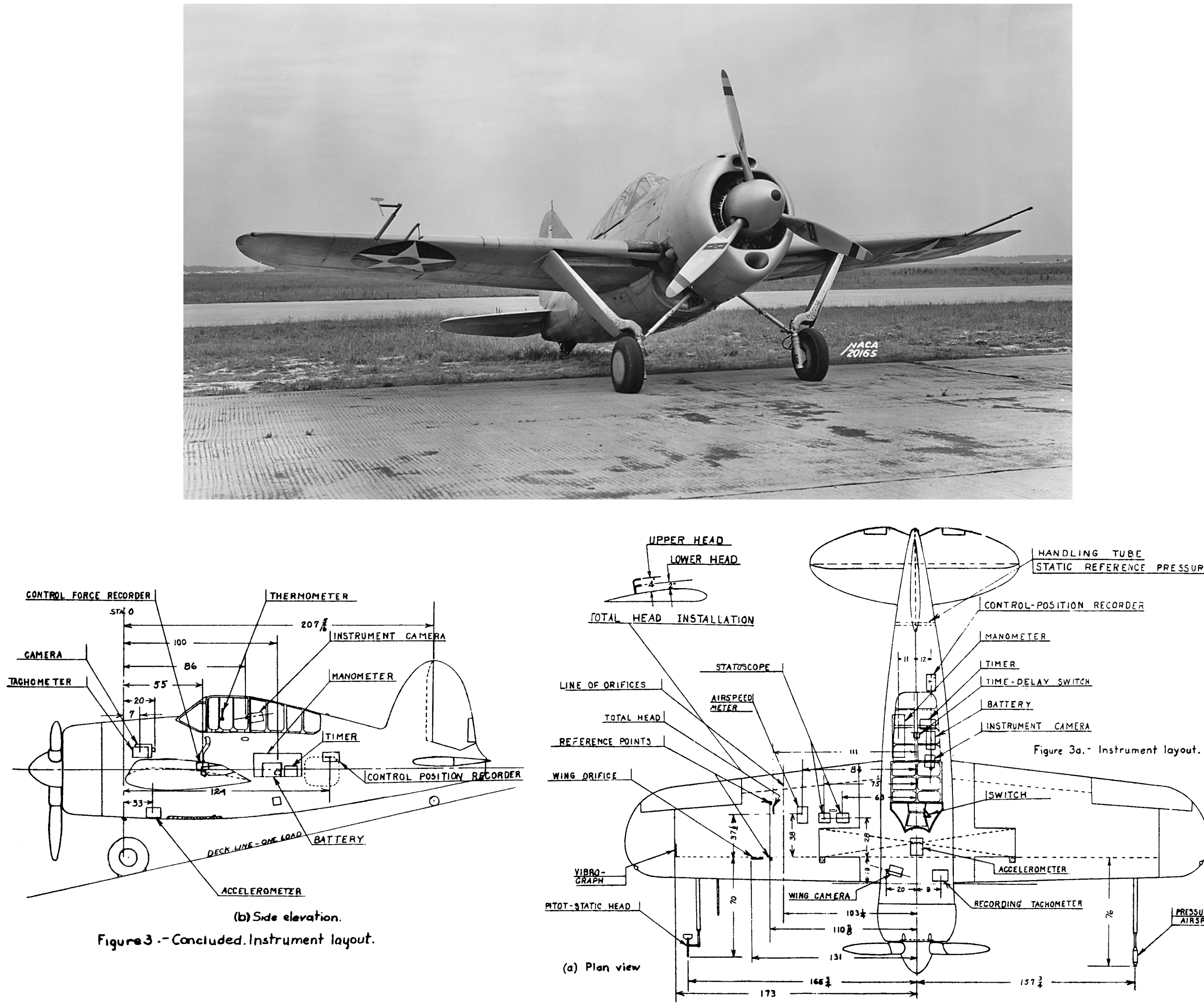


Fig. 6 Details of the specially instrumented XF2A-2 at Langley Field, spring 1940.

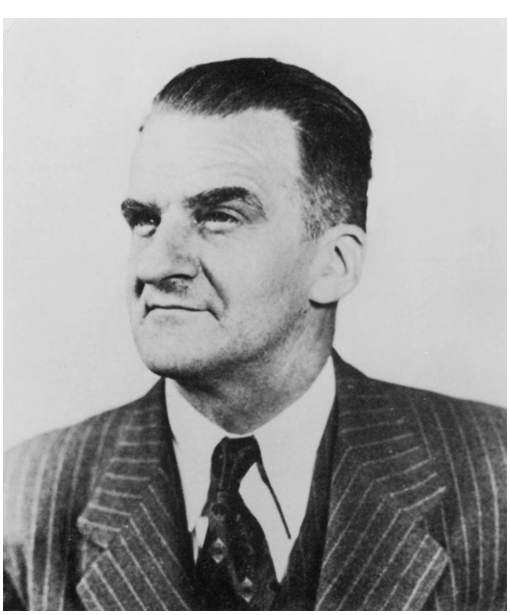


Fig. 7 The famous Theodore Theodorson, who analyzed and solved the potentially lethal flutter situation.

Osborn. Using these data with basic flutter equations he had developed in a confidential LaRC memo, Theodorson's resulting preliminary estimates[13] soon made it clear that there could be an aileron unbalance problem leading to possible flutter in the speed range planned for the dive tests. While Theodorson estimated the amount and placement of the balancing weight needed to cure the problem, Dick Rhode hurriedly contacted Captain Moore at Wright Field (of P-36 dive fame) to get his recommendations on a flightworthy means of attaching the new balancing weights.[14] Because the calculations had indicated possible wing flutter in the aileron bending mode near 450 mph, the ailerons were altered to be slightly nose-heavy about the hinge line. Working around the clock, Hank Pearson accomplished this overbalancing by attaching $\frac{1}{32}$-in. lead sheets to the aileron leading eyes with doped fabric in the manner suggested by Capt. Moore (see Fig. 8); this raised the estimated flutter flight speed to nearly 600 mph, which was deemed sufficient for these tests.[15] In the process, Theodorson had also found the tail control surfaces to be excessively out of balance, and so a total of eight more pounds of lead was added to these surfaces as well.

The Dive Tests

Dive Test Series

The flight test program was conducted in three phases, as follows: 1) preliminary flights to check the instrument operation, to calibrate air speed installation, to locate suitable static pressure

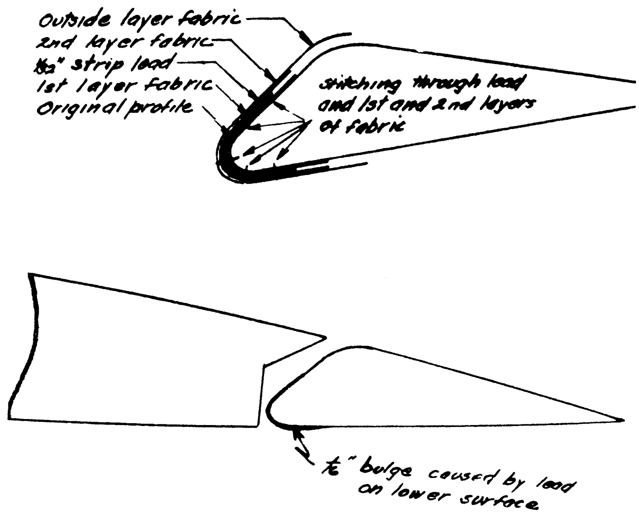


Fig. 8 Details of balance weight added to aileron for flutter prevention.

reference points, to check the position of the total head tube relative to the boundary layer, and to obtain some preliminary pressure distribution data at low speeds; 2) practice dives for familiarization to check the behavior and stability of the airplane at increasingly severe speeds and accelerations, and to calibrate the indicating accelerometer against the VG recorder; 3) The contract dives at three different speeds, to obtain complete data throughout the range of Mach numbers and lift coefficients designed to produce supercritical flow on the wing.

The preliminary flights were carried out over the 4-day period 19–22 April 1940 by both MacAvoy and resident NACA test pilot Mel Gough.[16] The phase 2 practice dives were then begun on 23 April by Woody Burke, who in the meantime had arrived from Brewster. From 23 to 27 April, five different practice dives were carried out by Burke and MacAvoy plus one by Gough. Events went smoothly in the first four dives: with the aircrafts' center of gravity at 28% chord, it responded satisfactorily although increasing unsteadiness in the VG record became cause for concern in view of the smooth air conditions that had prevailed. Then in the fifth dive, on 25 April, disaster nearly claimed Woody Burke's life; during the pullout, he had blacked out and lost elevator control, with the result that the aircraft experienced a very high angle of attack and acceleration during pullout of over $11g$. Subsequent assessment indicated that the airplane survived this loss of control because supercritical flow on the wing had induced a nose-up pitching moment that caused the airplane to pull up into a climb while Burke was blacked out. A further forward center of gravity shift to 30% was implemented, which ensured ample longitudinal stability for the remaining tests; a sixth check dive was then carried out without incident.

The program moved into its final phase involving the contract dives by Burke. The first of these was on 29 April: a vertical dive and pullout with a normal acceleration of $8g$, involving air speed of not less than 300 and not more than 325 mph. That afternoon a second dive was carried out with again an $8g$ acceleration but with an air speed slightly less than 400 mph. MacAvoy and Gough subsequently took the Brewster up for several hours of unscheduled test flights to check out various stability features. Then on 7 May the contractual test diving was resumed by Burke, this time going all out to reach supercritical wing flow conditions. In the morning Burke took the ship out for a 300+-mph dive with an $8g$ pullout, which indeed produced the desired supercritical pressure distribution on the wings, and then that afternoon followed up with a 425-mph dive, which also produced supercritical flow conditions (Figs. 3 and 4). For the next 6 days, the airplane was grounded for checkout of the airframe and instrumentation while the test data were digested. On 13 May, Burke executed a fifth official contract dive, this time going for a terminal velocity dive condition around 435 mph with an $8g$ pullout; this produced indeed a very substantial pocket of supersonic flow on the wing with a flight Mach number of 0.72. The airplane then again sat idle for nearly another 2 weeks while the results were digested. Following some checkout flights by MacAvoy and Gough from 27 May to 1 June, Burke took the Brewster up for the last time on the morning of 5 June for its final scheduled contract dive, a terminal velocity dive from 30,000 ft with a pullout supercritical flow on the wing. That very afternoon, Burke returned to Brewster. The next day, Navy Lt. Dixon flew the XF2A-2 to Newark for removal of the test instrumentation, restoring it to its original configuration.

Test Results

Rhode and Pearson provide a detailed discussion[12] of the accuracy, calibration procedures, and data reduction methods for the measurement of flight speed, acceleration, drag coefficient control surface forces and displacements, and wing section pressure distributions (among other items). For example, they estimated that the critical Mach number (at which sonic flow occurred near maximum airfoil thickness) was accurate to 0.01; many of the test conditions extended well beyond this Mach number, corresponding to an ultimately determined maximum dive speed of 560 mph.

A typical time-history flight record of such measurements from the 7 May 1940 supercritical dive is reproduced here in Fig. 3. Of particular interest are the corresponding wing strip chordwise pressure distributions—shown in Fig. 4—which clearly show the unmistakable pressure of a local shock wave around 10–15% chord downstream of the leading edge. A number of other comparable records from the various dive tests may be found in Ref. 12. All of the data made it evident that the test conditions extended well beyond the critical number of the wing test section with a local shock that was steady. The data also indicated that the observed variation of lift curve slope with Mach number was quite similar to what had been expected from wind tunnel studies, namely an increase in the subcritical range followed by a rapid drop beyond the critical Mach number and then an increase again.

Because one of the original rationales for the dive tests was the validation of wind tunnel data, John Stack (Fig. 9) wasted no time in exploiting these results; indeed, while the flight test program unfolded, he and his colleague B. N. Daley had carried out in the spring of 1940 an "unofficial" series[17] of airfoil model tests in Langley's then-new 24-in. transonic wind tunnel. A 5-in. chord NACA 23012 smooth airfoil model made of diraluminum,[1] was instrumented with pressure taps and was tested in the freestream Mach number range from 0.50 to 0.74. These exploratory results, highly classified at the time, were then compared with the XF2A-2 flight test pressure distributions nominally pertaining to the same airfoil section: Fig. 10 illustrates some of the direct comparisons between the two. The generally favorable agreement shown in this figure served at the time to

Fig. 9 John Stack, the legendary Chief of Compressible Aerodynamics at Langley, who set up unofficial comparative tests using the new NACA Transonic Wind Tunnel.

Comparison of flight and wind tunnel pressure-distribution measurements for $C_n = 0.4$; airplane wing, NACA 230-series section 14⅓ percent thick; wind tunnel model, NACA 23015 section.

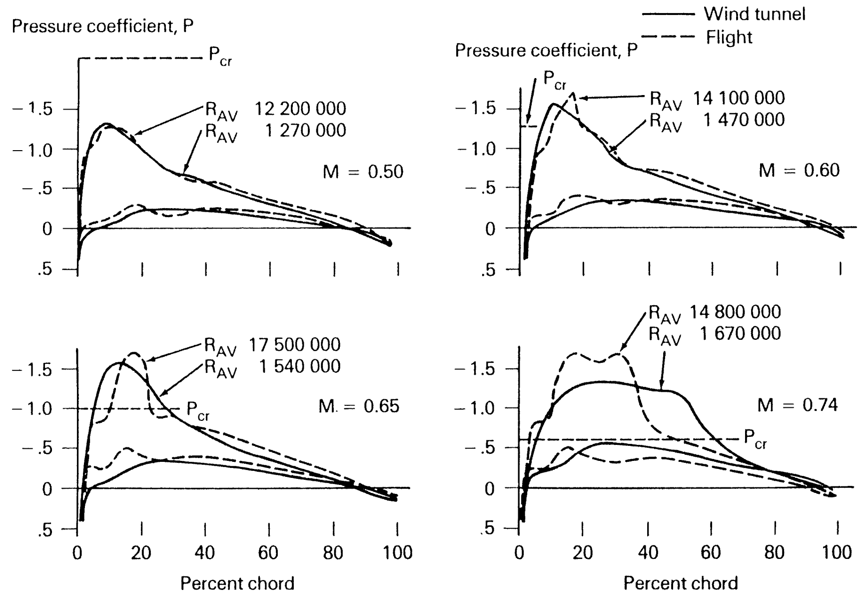


Fig. 10 An aeronautical first: direct comparison of supercritical flight pressure distributions to validate NACA transonic wind-tunnel data.

validate the data coming out of the new Langley transonic tunnel, an important step in the fledgling field of transonic aerodynamics. [Stack and Rhode ascribed many of the irregularities in the flight data (evident in Fig. 10) to unevenness in the wing surface associated with the rough and slightly wavy riveted skin of the XF2A-2.] Viewed another way, these results showed that the principal effects of compressibility indicated by wind-tunnel tests at supercritical speeds are also manifested under flight conditions. But the achievement, like the flight test, would not be publicized (owing no doubt to the rapid approach of WWII): it would be 3 years later before the results of this validation study would be documented, and then only as a classified[18] NACA advanced confidential report (ACR) issued early in 1941.

The Aftermath

Dissemination

By 12 June 1940 BurAer had been formally notified as to the successful completion of the test program,[15] while the unofficial word spread quickly throughout the U.S. aeronautical community. Requests for details and discussion visits came into Langley from both Wright Field and various aircraft manufacturers such as Vought (then involved in developing the XF4U-1 "Corsair"), Curtiss, and Douglas. In response, Rhode and Pearson wrote a confidential memo report dated 29 August, which was forwarded to BurAer on 4 September; by the end of the month, the Navy had authorized distribution of it to all AAC and USN aircraft contractors. The new engineering insight into compressibility effects afforded by the XF2A-2 dive program had clearly stimulated widespread interest.

Having been involved in a support role (regarding the control balancing aspect), Wright Field in particular was stimulated into considering a similar program with one of its new pursuit fighters; by June 1941, it had in fact undertaken preliminary planning for a compressibility study with the Bell P-39 "Airacobra."[19] However, by early 1942 the P-39 had fallen from favor as a viable candidate owing to its failure to pass dive acceptance tests involving 500+-mph/7+g pullouts, as well as Bell's unwillingness to contract for such tests. Ultimately, the Army chose the more viable P-47C "Thunderbolt" and then the prototype XP-51 "Mustang" for instrumented dive tests in 1943 and 1944, which involved much of the flavor of the 1940 Brewster project.[20]

During all this time, the formal release of Rhode and Pearson's report had been held in abeyance because of its obvious importance to wartime military aircraft design secrecy. It was finally approved as a confidential ACR in March 1943 (Fig. 11), about the time of the Wright Field P-47C dive tests, which had benefited much from the contents. Indeed, the report was often cited in the subsequent NACA transonic aerodynamics literature well into 1944 (see, e.g., Ref. 21).

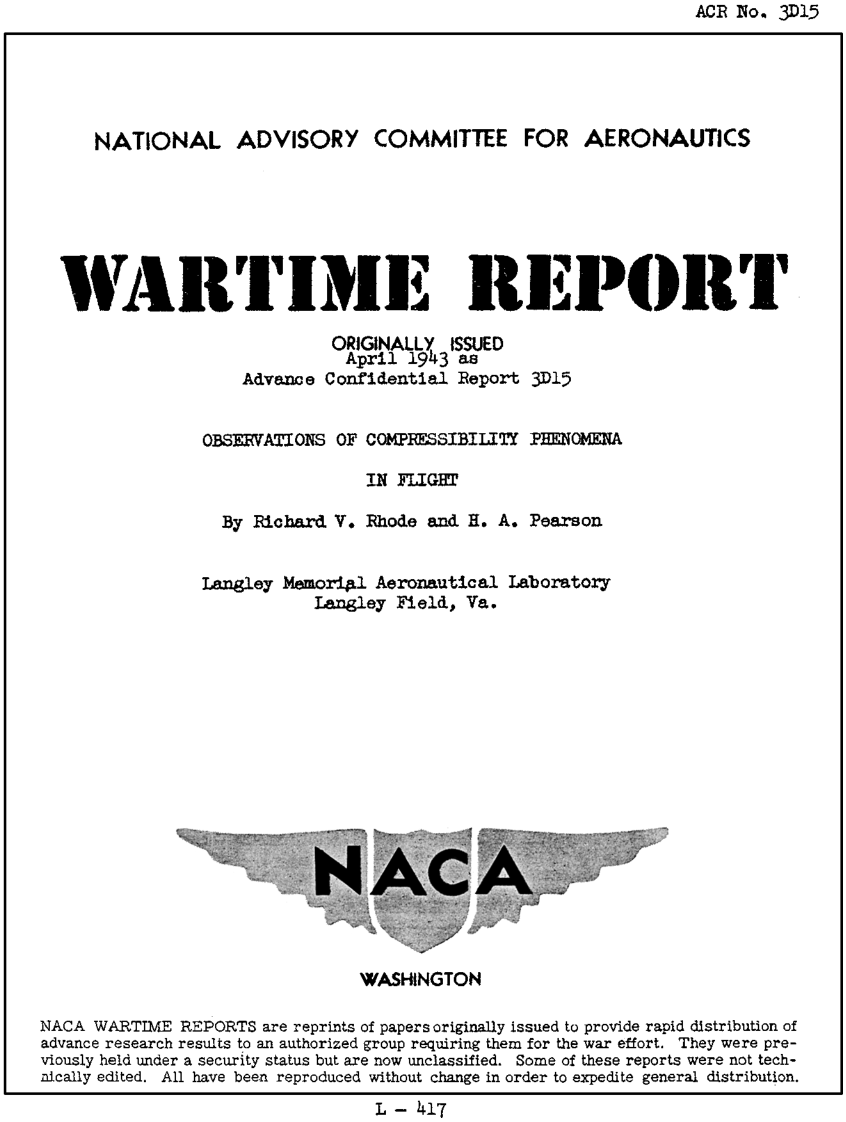
No Respite for "0451"

And what subsequently became of the XF2A-2 "Peanut Special"? Following its deinstrumention from the dive tests, it was returned to Brewster for finishing trial-board modification and flight testing at Anacostia pursuant to a production contract as the F2A-2. But BurAer had still further plans for using NACA to explore Navy fighter improvements using 0451: on 25 October 1940, it was returned to Langley to undertake full-scale wind tunnel tests (under RA 796) involving drag reduction, cowling clean-up studies, and, finally, a study of the aerodynamic effects of various candidate wing gun installations including 20-mm cannon.[22] Figure 12 shows a photo of the XF2A-2 installed on the balance supports of the Langley full-scale wind tunnel as of November 1940. The airplane remained at Langley for this test program until 9 June 1941; the results were subsequently documented in a group of confidential ACRs.[23,24]

The XF2A-2 never returned to Langley after 1941; although there had been some earlier plans for NACA to carry out further flight quality investigations, these were not realized owing to the press of evaluating newer, more promising Navy and Army aircraft designs. The record of the aircraft at this point becomes fragmentary, although a BurAer report[25] shows it still being carried on the inventory as of 27 August 1942. Shortly after, its very useful career finally spent, the XF2A-2 was surveyed as a derelict trainer in Miami.[26]

Epilogue

Viewed in retrospect, the 1940 NACA/BurAer project is important because it was a serious, well-planned engineering study of an important new aerodynamic phenomenon (compressibility effects)—and not simply another "dive it as fast as you can to see if the wings stay on" type of activity. Specifically, the project resulted in a number of significant contributions: 1) It provided the



ACR No. 3D15

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
April 1943 as
Advance Confidential Report 3D15

OBSERVATIONS OF COMPRESSIBILITY PHENOMENA

IN FLIGHT

By Richard V. Rhode and H. A. Pearson

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NACA

WASHINGTON

NACA WARTIME REPORTS are reprints of papers originally issued to provide rapid distribution of advance research results to an authorized group requiring them for the war effort. They were previously held under a security status but are now unclassified. Some of these reports were not technically edited. All have been reproduced without change in order to expedite general distribution.

L – 417

Fig. 11 The final report on the project, which only appeared three years later as confidential NACA wartime report ALR-3D15.

Fig. 12 XF2A-2 mounted on the Langley full-scale wind tunnel for drag-reduction studies following the flight compressibility project. (Photo courtesy NASA Langley Archives via Susan Seward.)

first flight data for validation of the then-new transonic wind-tunnel airfoil tests at NASA Langley. 2) It validated the proposed method for estimating the critical Mach number of an airfoil. 3) It firmly established the extent of the local supersonic flow pocket on an airfoil at supercritical flight speeds and its Mach number dependence. 4) It focused attention on the controllability aspect of the transonic flight regime by virtue of the aileron rebalancing problem that arose. Even a casual inspection of the long-lost documenting report[12] still engenders admiration for the expertise and vision of the people involved so long ago in 1939–1940.

Acknowledgments

I express my deep appreciation to three people for their help during the extended research for this paper: First, to the late Richard Rhode, who as a major architect of the 1940 Dive Project provided a fountain of information and insight during my 1985 interview visit to his Bethesda, Maryland, retirement home; second, to James Hanson of the Auburn University History Department, who unselfishly took time off from writing his subsequently acclaimed book[27] on Langley history to instruct me in the workings of Langley's History Office Records, especially the RA System formerly used there; and third, to Susan Seward, former Research Librarian at Langley, who took my needs to heart and repeatedly provided amounts of research material to flesh out the NACA/XF2A-2 story.

References

[1]Becker, J. V., *The High Speed Frontier*, NASA SP-445, 1980, p. 88.

[2]Beauchamp, G., and Cuny, J., *Curtiss Hawk 75*, VIP Publishers, Colorado Springs, CO, 1996, pp. 107–109.

[3]"High Speed Dives for French Purchasing Commission," *Popular Aviation*, May 1939, pp. 8–10.

[4]"More Power Dive Speed Estimates," *Kansas City Kansan*, 8 Feb. 1939, p. 2.

[5]Pearson, H., "Request of Bureau of Aerodynamics for Comments on Damage to SBC-4 Airplane," Langley Memo to NACA Headquarters, Research Authorization File 705, Langley Historical Archives, 7 June 1939.

[6]Rhode, R. V., "Compressibility Failure on P-36 Airplane," Langley Memo to Cmdr. L. M. Grant of the Bureau of Aeronautics, Research Authorization 705, Langley Historical Archives, 4 Aug. 1939.

[7]Rhode, R. V., "Visit of Commander Grant and Mr. R. L. Creel to the Laboratory," Langley Memo to Engineer-in-Charge H. J. E. Reid, Research Authorization 705, Langley Historical Archives, 20 Sept. 1939.

[8]Reid, H. J. E., "Study of Effect of Compressibility Burble in Flight," Research Authorization 705, Langley Historical Archives, 19 Oct. 1939.

[9]Reid, H. J. E., "Request of Bureau of Aeronautics for Flight Investigation of Compressibility," Langley Memo to NACA Headquarters, Langley Historical Archives, 24 Oct. 1939.

[10]"Experimental Tests on XF2A-2 Airplane," Contract Document BurAer 70851 with Brewster Aeronautical Corp., Research Authorization 705, Langley Historical Archives, 2 Dec. 1939.

[11]Reid, H. J. E., "XF2A-2 Dive Tests—Request for Information," Langley Memo to NACA Headquarters, Research Authorization 705, Langley Historical Archives, 4 Jan. 1940.

[12]Rhode, R. V., and Pearson, H. A., "Observations of Compressibility Phenomenon in Flight," NACA WR L-417, Advanced Confidential Rept. ACR 3D15, Washington, DC, April 1943.

[13]Theodoreson, T., "Flutter Analysis on the Brewster XF2A-2 Airplane," Langley Memo to Dr. Lewis of NACA Headquarters, Research Authorization 705, Langley Historical Archives, 6 May 1940.

[14]Reid, H. J. E., "XF2A-2 Dive Tests—Information on Method of Balancing Control Surfaces Obtained from Materiel Division," Langley Memo to NACA Headquarters, Research Authorization 705, Langley Historical Archives, 12 June 1940.

[15]Lewis, G. W., "XF2A-2 Dive Tests—Completion of Tests," NACA Headquarters Memo to Chief of BurAer, Washington, DC, Research Authorization 705, Langley Historical Archives, 12 June 1940.

[16]Reid, H. J. E., "Specifications for Piloting Navy Model XF2A-2 Airplane in Special Flight Tests," Langley Memo to NACA Headquarters, Research Authorization 705, Langley Historical Archives, 21 May 1940.

[17]Stack, J., and Daley, B. N., "Comparison of Pressure Distribution Measurements for an NACA 230-series Airfoil from Flight and Wind Tunnel Tests at High Mach Numbers," NACA Advanced Confidential Rept., Langley Field, VA, Research Authorization 705, Langley Historical Archives, March 1943.

[18]Becker, J. V., "High Speed Wind Tunnel Tests of the NACA 23012 and 23012-64 Airfoils," NACA WR L-353, Advanced Confidential Rept., Washington, DC, Research Authorization 705, Langley Historical Archives, Feb. 1941.

[19]Pearson, H., "Dive Tests with P-39 to Determine Compressibility Effects," Langley Memo to H. J. E. Reid, Research Authorization 705, Langley Historical Archives, 30 June 1941.

[20]Abzug, M. J., and Larrabee, E. E., *Airplane Stability and Control*, Cambridge Univ. Press, Cambridge, England, U.K., 1997, pp. 155–157.

[21]Rhode, R. V., "Correlation of Flight Data on Limit Pressure Coefficients and Their Relation to High-Speed Burbling and Critical Tail Loads," NACA WR L-269, Advanced Confidential Rept. L4127, Washington, DC, Research Authorization 705, Langley Historical Archives, Sept. 1944.

[22]Silverstein, A., "Full Scale Wind Tunnel Test Program on XF2A-2 Airplane," Langley Memo to Chief of Aerodynamics, Research Authorization 705, Langley Historical Archives, 6 Dec. 1940.

[23]Preston, G. M., and Sweberg, H., "Cleanup Tests of the XF2A-2 Airplane in the NACA Full Scale Wind Tunnel," Confidential Memorandum Rept., Langley, Research Authorization 705, Langley Historical Archives, 21 Jan. 1941.

[24]Czarnecki, C., and Guranske, G., "Tests of Wing Machine Gun and Cannon Installations in the NACA Full Scale Tunnel," Advanced Confidential Rept., Research Authorization 705, Langley Historical Archives, 4 Aug. 1941.

[25]Towers, J., "To All Stations and Ships re All F2A Airplanes," Memo from BurAer Chief, Research Authorization 705, Langley Historical Archives, 27 Aug. 1942.

[26]Maas, J., *F2A Buffalo in Action*, Squadron Signal Publications, Carrollton, TX, 1987, p. 45.

[27]Hanson, James R. *Engineer-in-Charge; A History of the Langley Aeronautical Laboratory*, NASA History Series, NASA, Washington, DC, 1987.

A. Springer
Associate Editor