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The Operation of the Bell XS-1 Aircraft by Captain Charles E. Yeager

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The purpose of this portion of the presentation is to present the operational procedure and flight characteristics of the XS-1 aircraft during the accelerated test program which has recently been conducted at Muroc Lake. The activities of the Flight Test Division personnel in connection with this program will be the primary part of this report. For obvious reasons I shall make it as brief as possible and shall depend upon your questions during the ensuing question period to clarify any points which I do not cover in detail.

In a conference between personnel of the Bell Aircraft Corporation, the NACA, and AMC on 30 June 1947, it was decided that an expedited test program on the XS-1 would be conducted at Muroc Lake. The primary function of the Flight Test Division was to be the operation of the No. 1 XS-1 and the B-29 mother airplane. In addition such maintenance and technical assistance would be made available as required. The primary aim of this program was to be the investigation of transonic flight phenomena as experienced in the XS-1 up to a Mach number of 1.1. It was decided to proceed through this range of Mach numbers on consecutive flights as rapidly as common sense and technical considerations would permit. The flight program was initiated on 6 August with a series of glide flights, and some indication of the success of the program may be had from considering the fact that the original goal was reached on the ninth powered flight on 14 October. Immediately following this flight a recapitulation of the progress that had been made to that date was made in a conference at Wright Field and an additional flight test program was determined. To this date a total of 16 powered flights have been completed with results that have been detailed in other portions of this presentation.

Since the primary purpose of this paper is to give you some of the details of the operation of the aircraft involved, I shall make an attempt to cover at some length one of the powered flights that have been conducted and then briefly sketch the pertinent points of other flights. Let us consider a normal flight and the details of operation. On the day before the flight the XS-1 pressure system is loaded with nitrogen gas and a pressure check is made up to normal operating pressure to check for any leaks that might have developed since the system was last pressurized. The XS-1 is then loaded into the mother airplane the evening before the flight to provide as little delay as possible in getting an early start the following morning. Early the next morning the B-29 is towed to the liquid oxygen and nitrogen storage tanks where immediate action is taken to bring the nitrogen pressure up to operating conditions. While this is being accomplished the lox (liquid oxygen) and fuel tanks are serviced so that a minimum of delay is incurred after the nitrogen pressure has been raised to the needed 4800 pounds per square inch. Just prior to disconnecting the pressure lines the B-29 propellers are pulled through and pre-flight inspection is completed. A last minute briefing with the chase pilot is accomplished to insure that all personnel concerned understand thoroughly the nature of the day's flight and the responsibility of each person. As the B-29 is towed into a position where the engines may be started, the nitrogen bleed for the XS-1 rocket motor is connected to a bottled source in the B-29 to conserve source pressure in the main nitrogen tanks in the XS-1. This is made even more critical due to the unavoidable loss in source pressure from cooling as altitude is gained, and ~~from absorption of nitrogen by the liquid oxygen~~ BLEEDING OFF THROUGH The motor. A minimum of delay is necessary in all operations after this point to insure sufficient pressure for dropping at as high an altitude as is practicable. The take-off of the mother ship is normal and immediate climb to altitude is started. After an altitude of 7000 feet is attained, I proceed to the cockpit of the XS-1 by way of the ladder from the B-29 bomb bay.

In this I am assisted by the project engineer who hands down the door of the XS-1 which I fasten from the inside of the airplane. As the B-29 continues to climb, the cockpit of the XS-1 is pressurized and I proceed to connect up the radio, oxygen mask, and other necessary harness to secure myself in the cockpit. Three minutes before drop time I am in contact with the crew of the B-29 and notified of the proximity of the drop. It is now time to load the first stage regulator, and in turn the fuel tank and lox tank are pressurized. These tanks maintain a pressure of approximately 330 pounds to propel the fuel and lox to the motor. However, due to lag in the pressure lines, this pressure drops to about 300 pounds when all four chambers are burning and the rate of fuel flow is high. Negative accelerations on the airplane also produce some variation in this pressure. Immediately before the drop a final cockpit check is made, instrumentation switches are turned on and final preparations for the drop are completed. The crew in the B-29 disconnects the nitrogen source from the B-29 and the XS-1 is ready for the drop. An indicated air speed of 250 mph, or slightly more, is desirable to maintain proper control of the XS-1 and to allow for a minimum loss of altitude in the glide before ignition of the rocket engine. Upon a counted signal transmitted from the B-29, the XS-1 is dropped from the mother aircraft and an acceleration of approximately .6 g is experienced as the glide is stabilized. After dropping approximately 800 feet all chambers are ignited in rapid sequence and a climb is started which stabilizes at an angle of from 30° to 40°. As the climb is started, the horizontal stabilizer is set at 2° leading edge up, and a Mach number of approximately .85 is usually maintained throughout the climb.

Approximately 10,000 feet below the test altitude two of the chambers are turned off to reduce the angle of climb and to establish level flight at approximately .85 Mach number before continuing the tests. The procedure as outlined up to this point is approximately the same for all flights with only

A FEW NECESSARY CHANGES CAUSED ~~those variations necessitated~~ by operational difficulties. For instance, on one flight the release solenoid for the bomb shackle which holds the XS-1 in the mother airplane failed to operate. By the time the airplane could be released mechanically the air speed had fallen below the desired launching speed and the XS-1 was released in a partial stall. Although this was not considered too slow for safety of release, the XS-1 lost approximately 5000 feet before a powered climb could be initiated. On another occasion the reduction of source pressure in the XS-1 was so rapid that the minimum safe release pressure of 3700 pounds was encountered and a release at 20,000 feet was necessary. It has been pointed out elsewhere that the lower altitude of release penalizes the performance of the airplane under its own power since more fuel must be used to climb from the lower altitudes.

I shall now attempt to give you my impression of the flying characteristics of the XS-1. All comments hereafter will be related to Mach numbers as that is the primary speed indication for this test program. The Mach numbers mentioned will be true Mach numbers as corrected and reported by the NACA to eliminate the possibility of confusion which might be induced by a consideration of the correction due to static source error through the range of Mach numbers encountered in this flight test program. During the first portion of the flight test program the progress was quite slow and a number of flights were used to become familiar with the airplane and its operation. The Mach number was increased in fairly small increments to insure maximum safety in the test program, and as more familiarity with the airplane was attained the program was accelerated.

Rapid acceleration is realized as each of the four power units are ignited, and as The climb is initiated an effective shift in CG to the rear seems to require nose down trim. The first powered flight runs were made at the 30,000 to 35,000 foot level, and an effort was made to obtain buffet boundaries and stall information. This was necessary to correlate model test data, and the information obtained on each flight was used in planning succeeding flights. From a Mach number of .8 to approximately .87 very little change in trim was noticeable from the cockpit. An analysis of the data showed that this was partially because of the light stick forces involved. An elevator displacement of only 1° to 2° was necessary to compensate for pitch change in the nose down direction. At a Mach number of .87 a light buffeting was encountered which in turn seemed to induce a very moderate lateral instability. The right wing became noticeably heavy and an aileron displacement of approximately 3° was necessary to maintain level flight.

This right wing heaviness appears to be noteworthy since it continues to exist through the transonic range to a Mach number of approximately 1.3 with an increase in aileron forces as the Mach number increases. It is believed that this is possibly caused by the scuffed surface of the right wing.

As the Mach number was increased from .87 the buffeting became more severe and a nose down trim change was noted. The forces were quite light and the movement of the control column remained the best means of indicating the trim change. At approximately .90 Mach number trim change previously mentioned reversed and the tendency was for the nose to rise and in the range of approximately .92 Mach number the buffeting became quite severe.

At this point in the program it was decided from a correlation of model test data that the one degree per second actuator for the stabilizer might prove to be too slow for proper control during subsequent flights and an interruption in the program was made to install a faster motor. In the first flight after the new stabilizer actuator was installed the Mach number was increased to .94. At this point the trim change <u>again reversed</u> to a nose down tendency but it was still easily controllable and approximately 3° of up elevator provided level flight. From .94 to .96 the elevators and rudder became increasingly ineffective until at the latter figure they could be moved throughout their range of displacement with very slight response from the aircraft. At approximately .95 the buffeting decreased rapidly and became non-existent at .96.

Up to this time a stabilizer setting of 2° leading edge up was used in all of the high speed test runs. The next flight was therefore initiated to investigate the effectiveness of control by the stabilizer at the higher speeds above .96 since the setting had only been varied in climbs up to this time. As the speed was increased on this flight the stabilizer was changed to 1-1/2° leading edge up and returned to 2° leading edge up successively at .84, .88 and .95 Mach numbers. The acceleration experienced in the cockpit was approximately the same for all speeds and it was decided that the stabilizer was still effective even though the elevator and rudder had lost their effectiveness. The ailerons remained effective throughout the range. With the stabilizer setting of 2° the speed was allowed to increase to approximately .98 to .99 Mach number where elevator and rudder effectiveness were regained and the airplane seemed to smooth out to normal flying characteristics. This development lent added confidence and the aircraft was allowed to continue to accelerate until an indication of 1.02 on the cockpit Mach meter was obtained. At this indication the meter momentarily stopped and then jumped to 1.06 and this hesitation was assumed to be caused by the effect of shock waves on the static source. At this time the power units were cut and the airplane allowed to decelerate back to the subsonic flight condition. When decelerating through approximately .98 Mach number a single sharp impulse was experienced which can best be described by comparing it to a sharp turbulence bump. This point is mentioned since it has occurred on all subsequent flights and an explanation of its cause does not seem to be completely obvious.

As was mentioned previously, the program was interrupted at this point and a decision was made in conference with Bell Aircraft and AMC personnel to continue the program to attempt to attain a full-power stabilized high speed run. Perhaps it should be mentioned at this time that the high speed attained thus far was accomplished on 75% power in an unstabilized flight condition.

After the resumption of the flight test program the speed was gradually increased in relatively larger increments to a corrected Mach number of 1.35. The buffeting and instability as mentioned heretofore was encountered at the same Mach number each time and as might be expected appeared much less serious as altitude was increased. The maximum Mach number of 1.35 was attained in a flight on 6 November 1947 at an altitude of 48,000 feet. This corresponds to a true air speed of 910 mph. Since I was unable to ignite the No. 3 chamber on this flight due to malfunction of the igniter, this speed was attained in a shallow dive from approximately 52,000 feet.

It is probably desirable at this time to mention the extent of the maneuvering which has been accomplished at higher Mach numbers. At Mach numbers in excess of 1, gentle turns and climbs have been made without difficulty, and except for the expected higher control forces the flight characteristics seemed to be quite normal. Stalls have been performed at various altitudes at subsonic Mach numbers to investigate the variation of maximum lift coefficient with Mach number.

At the conclusion of each test the small amount of fuel remaining in the airplane is jettisoned and a relatively low speed glide to lower altitudes is started. On some flights additional accelerated stall information has been obtained in the glide since a definite weight fix is attainable when all the fuel has been jettisoned. The practice of jettisoning the last portions of the fuel has been used to prevent possible malfunction of the rocket motor by permitting the fuel to become completely exhausted while the motor is running.

An unaccelerated stall with gear and flaps down is usually performed at a lower altitude for a landing reference and to insure that all fuel and lox has been jettisoned. The stalling speed in this condition is approximately 135 mph and touch down is usually made at approximately 140 mph. Ten to twelve thousand feet of roll is necessary to stop the airplane without brakes.

With reference to the planning of succeeding test flights, this is usually accomplished in conference with NACA and Flight Test Division personnel on the day preceding the proposed flight. The NACA personnel express their desires as to what data would best augment their technical report, and offer advice as to what might be expected in the range to be explored next. The final decision as to how much advancement in the program is to be made on any particular flight is left with the Flight Test Division crew. As has been indicated previously, some changes are necessarily made during the course of the flight.

It is expected that two or three more flights will be required to complete the current phase of the test program. Since the last flight on 6 November, some delay has been experienced due to maintenance difficulties on the mother aircraft and the installation of a new windshield on the XS-1. In view of speeds already obtained, it is considered quite likely that a Mach number of 1.6 can be attained during the completion of this phase with 100% power and possibly a slight dive.

X-1A FLIGHT #10 12 Dec 53

DeYoreo:	Roger we're all clear to drop at anytime.
B-29 Pilot:	Okay I'm building up speed, 32,000 feet now, 210 miles an hour. Charlie, when I kick you out, you will probably be about approximately 10 miles North of Victorville on a heading of 280°.
Yeager:	Okay, Boy, make sure it's a minute when you drop me. It's about 30 seconds from now, I reckon.
B-29 Pilot:	Okay. You give me the work for the count down.
Yeager:	Okay, start your count down slowly.
B-29 Pilot:	Okay, starting count down starting from 5 down to zero. 5 - 4 - 3 - 2 - 1 Okay, drop her Danny.
Co-Pilot:	DROP
Yeager:	Firing 4.
Chaser (Ridley)	No light, just fuel.
Yeager:	Is it on now?
Chase: (Ridley)	Yes

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Yeager:	Fired #2.
Bell Truck:	What cylinders are on, Chuck?

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Yeager:	#3 coming on now. Start.
Yeager:	Cylinder seconds on 250 right now.

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Yeager:	Cylinder seconds back to 97 right now.
Bell Truck:	We have your time, Chuck.
Yeager:	Okay.
Yeager:	Push Over.
Bell Truck:	20 seconds.

Chase: (Ridley)	Got him in sight, Kit?
Chase: (Murray)	No, He's going out of sight - too small.
Yeager:	Illegible - gasping - I'm down to 25,000 over Tehachapi. Don't know whether I can get back to the base or not.
Chase: (Ridley)	At 25,000 feet, Chuck?
Yeager:	I can't say much more, I got to (blurry - save myself).
Yeater:	I'm - - - (illegible) - - - - (C - - - -t!)
Chase: (Ridley)	What say, Chuck?
Yeager:	I say I don't know if I tore anything up or not but C——t!
Chase: (Murray)	Tell us where you are if you can.
Yeager:	I think I can get back to the base okay, Jack. Boy, I'm not going to do that any more.
Chase: (Murray)	Try to tell us where you are, Chuck.
Yeager:	I'M (gasping) I'll tell you in a minute. I got 1800 lbs source pressure.
Yeager:	I don't think you'll have to run a structure demonstration on this d——d thing!
Chase: (Murray)	Chuck from Murray, if you can give me altitude and heading, I'll try to check from outside.
Yeager:	Be down at 18,000 feet. I'm about —— I'll be over the base at about 15,000 feet in a minute.
Chase: (Murray)	Yes Sir.
Yeager:	Those guys were <u>so</u> right!
Yeager:	Source pressure is still 15 seconds, I'm getting OK now.
Yeager:	I got all the oscillograph data switches off. 4 fps camera off, it's okay.
Bell Truck:	Jettison and vent your tanks.
Yeager:	I have already jettisoned. Now I'm venting both lox and fuel. Leaving hydrogen peroxide alone.

Bell Truck:	Roger.
Yeager:	I out it, I got - - in real bad trouble up there.
Yeager:	Over the base right now, Kit, at 14,500 feet.
Chase: (Murray)	I have you.
Yeager:	Does everything look okay on the airplane?
Chase: (Murray)	I'm still catching up to you.
Yeager: 1/2	Going to do a 360° here to the left.
Chase:	I don't have you, that's a T-33.
Yeager:	I'm right over the end of the diagonal runway - right over the North - South runway at the 3 1/2 mile marker. I'm going to make a right hand pattern.
Yeager:	Gear coming down. Source pressure still 1650. Gear down and locked.
Yeager:	Kit, got me in sight yet?
Yeager:	Huh?
Chase (Murray)	Negative.
Yeager:	Come down to 12,000 feet on a right hand downwind leg over the end of the Wast - West runway in the south end of the lake.
Chase: (Murray)	All right, roger, I see him.
Chase: (Ridley)	Got him, Kit?
Chase: (Murray)	Yes.
Yeager:	Flaps coming down.
Yeager:	Source pressure still 1600.
Yeager:	I'm a little bit fogged up - not too bad.
Chase: (Murray)	No, I don't have you, Chuck.
Yeager:	I'm on the base leg, I'll be landing on 35 right in a minute.

Major Thompson: (on ground)	Kit, swing to the right sharp, clear down on the edge of the lake bed, this is Tommy.
Yeager:	I'll be down over the South track there in a minute, down to 7,000 feet.
Chase: (Murray)	Roger.
Yeager:	Going to land a little long, I would appreciate if you'd get there and get this thing off (meaning pressure suit). I'm hurting.
Major Thompson:	On the final, Kit.
Yeager:	Just over the edge of the lake right now, Kit, got about 220 indicated.
Major Thompson:	Right in front of you, Kit, to your right. Down below you to the right, Kit.
Yeager:	1550 everything is all right. By G— I told you that —— that counter went around twice.
Chase: (Murray)	Coming off 50 - 30 - 20 - 20 - 20 - 5 - 2 - holding about 2 1/2 - 2 - 1 - looks good, mighty fine.
Yeager:	You know, if i'd had a seat you wouldn't still see me in this thing.
Bell Truck:	Chuck, did your suit blow on you?
Yeager:	No, it never did. I opened the - uh - it got up to about 43 thousand and I opened the windshield defroster and it went back down. I think I busted the canopy with my head. I don't know.
Bell Truck:	WOW!