WADD TECHNICAL NOTE 60-296

F-102 HIGH-ALTITUDE FLAMEOUTS IN AND AROUND THUNDERSTORMS

Philip I. Paul, 1st Lt, USAF

Flight Test Division
Flight and Engineering Test Group

JANUARY 1961

WRIGHT AIR DEVELOPMENT DIVISION

NOTICES

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Project Nr 201A(1)

WRIGHT AIR DEVELOPMENT DIVISION
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

100 – May 1961 – 29-1108

FOREWORD

This report was prepared by 1st Lt Philip I. Paul, project engineer, of the Adverse Weather Section, Flight Test Engineering Branch, Flight and Engineering Test Group, Wright Air Development Division, Wright-Patterson Air Force Base, Ohio, under project 201A(1), "Investigation of F-102 High-Altitude Flameouts in and Around Thunderstorms." Captains Kenneth H. Coffee and Charles E. Klobassa, Fighter Operations Branch, Flight and Engineering Test Group, were project pilots.

Flight test portions of the program were conducted at Wright-Patterson AFB, Ohio, during the summer of 1959, and at Oklahoma City, Oklahoma, in conjunction with the National Severe Local Storm Research Project "Rough Rider" which was conducted during April and May 1960. Rough Rider was initiated and directed by the U.S. Weather Bureau (Mr. C. F. Van Thullenar, director). USAF (WADD), FAA, and National Aeronautics and Space Administration were participants.

Flight operations at WPAFB were conducted in the R-109 area in south-central Ohio. Rough Rider flight operations were conducted from Tinker AFB within a 200 NM-radius of Oklahoma City.

Flight testing required the support of several other WADD aircraft including an F-100, F-101, F-106, T-33, and KC-135. All thunderstorm penetrations were accomplished under direction of an FAA radar controller. In-flight comments by test personnel were tape recorded; overlays of radarscope presentations were made for most of the flights; pictures were taken of a PPI radarscope. Information collected by a T-33 (NASA instrumented to obtain detailed information on structure, intensity and distribution of turbulence within the thunderstorms) which also flew in Rough Rider, will be used to compare reactions of straight wing and delta wing aircraft.

ABSTRACT

It was determined that mixtures of ice crystals and other precipitation commonly found in the core of thunderstorms at high altitudes constitute an extreme operating hazard to F-102 aircraft. The hazard can be relieved to a large extent by the installation and use of a continuous ignition system. It is recommended that the hard core or main precipitation area of the storm be avoided.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

JOSEPH DAVIS, JR.
Colonel, USAF
Commander, Flight and
Engineering Test Group

REVIEW AND COORDINATION OF WADD TECHNICAL NOTE 60-296

Author Approval

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INTRODUCTION

1. During the late spring and early summer months of 1959 a serious detriment to the mission of Air Defense Command (ADC) manifested itself in F-102A aircraft whose mission requirements included flights at high altitude in or near thunderstorms. The aircraft were experiencing a rash of compressor stalls and subsequent flameouts, as noted from incident reports received from all parts of the country and from overseas; but the greatest percentage of the compressor stall-flameouts occurred in the great plains states. Several F-102A's, representing millions of dollars, were lost in thunderstorms during 1959. Many others were saved only through expert piloting technique. ADC headquarters has on file detailed information concerning 54 individual compressor stall and flameout incidents.

2. In July 1959, ADC headquarters requested that ARDC initiate a program to investigate the cause of unexplained flameouts of F-102A aircraft at high altitude in or around thunderstorms, and to recommend action which would prevent such flameouts.

3. Testing commenced at WPAFB in August 1959. During the remainder of 1959 and early in 1960, an all encompassing test program was conducted in both natural and simulated thunderstorm conditions. All in-flight tests during this period were conducted in the R-109 area in south-central Ohio, which is an air space reserved for WADD flight test operations. Statistical data from ADC were carefully analyzed. As a result of this program, a valid solution to help prevent flameouts, and pilot techniques to reduce the compressor stall problem, were developed.

SCOPE OF DATA

4. Most early test data consisted of film coverage taken from other aircraft, inflight notes, pilot comments, and the incident reports provided by ADC.

5. High altitude compressor stalls were investigated both in a natural thunderstorm environment and under simulated conditions. Many factors, including different forms of turbulence, angle-of-attack, various types of precipitation, adverse throttle movements, use of speed brakes, use of wing tanks, various types of inlet duct design, etc., were investigated, both singly and collectively.

6. During Rough Rider operations, in addition to weather data and periodic plots of storm progress, pilot's panel indicator readings, engine performance, and flight parameters were recorded. F-102A thunderstorm penetrations were monitored on both the control station and weather bureau radar so that maximum advantage was taken of each storm situation. Pilot comment and de-briefings were recorded on tape.

TEST APPARATUS

7. In addition to the F-102A test aircraft, a KC-135 water spray tanker, another KC-135, an F-100F, an F-101, and an F-106 participated in the tests at WPAFB. The

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Manuscript released by the author 14 December 1960 for publication as a WADD Technical Note.

additional aircraft were required to run a complete J-57 engine and inlet duct analysis. To insure that test results were representative of F-102A aircraft/engine characteristics, two F-102A aircraft were used for the tests. The F-102A test aircraft was not instrumented for the flights conducted at the WADD testing area. A continuous ignition system with manual operation of the compressor interstage bleed valves was provided.

8. At Oklahoma City, the test aircraft (F-102A) carried full instrumentation. A T-33 served as a hail probe during thunderstorm penetration at Oklahoma City, Oklahoma. (See Figure 1, Appendix B).

FLIGHT PLAN

9. Test operations employed the following procedures in an attempt to induce engine compressor stalls in the test aircraft:

a. Unusual flight maneuvers such as extreme yaw coupled with pitch changes;
b. Rapid throttle movement at altitude;
c. Flight with both high and low engine trim adjustments;
d. High transient temperature changes;
e. Clear-air turbulence;
f. Ice-crystal ingestion;
g. Thunderstorm penetrations.

10. Test missions flown during the test program were as follows:

a. Flights in clear air in which attempts to induce compressor stalls were made by rapid throttle movements.
b. Flights in clear turbulent air at various altitudes and airspeeds. Turbulence was created by either wing-tip vortices or by the exhaust of a lead aircraft.
c. Flights in the ice-crystal spray created by a KC-135 tanker aircraft.
d. Flights through thunderstorms and cumulus clouds at various altitudes and airspeeds.

TEST PROCEDURES

TESTS AT WADD OHIO TEST AREA

11. Flights were made in south-central Ohio to determine the cause of the engine compressor stall problem. Attempts were made to induce stalls in clear-air turbulence and in thunderstorms by varying piloting techniques, aircraft altitude and attitude, airspeed, and flying conditions.

Adverse Throttle Movements

12. Two flights between 30,000 and 45,000 feet altitude were made to determine what effect rapid throttle increases or decreases had on the engine compressor stall problem. On one of these flights, the engine was trimmed 1 psi above maximum allowable exhaust pressure. No compressor stalls were induced by rapid throttle movements, even when the throttle movements were made during unusual pitch and yaw attitudes. (It is known that compressor stalls can be induced by retarding the throttle below the stall line for a given altitude; however, this is not the particular type of stall for which the information

was desired.) The results of these two flights indicated that rapid throttle movement was not the primary cause of the high-altitude flameouts and compressor stalls even when the engine is trimmed above maximum allowable exhaust pressure.

Airspeed

13. Seven flights were made to investigate engine performance in and around thunderstorms above 35,000 feet altitude. On four of these flights twelve penetrations were made within an airspeed range of Mach .75 to Mach .90. Eleven compressor stalls were noted for which no corrective action was required.

Clear-Air Turbulence

14. Simulated conditions were used to investigate the effect of clear-air turbulence on engine operation. Turbulence was obtained by flying the test F-102A into the wing-tip vortex created by an F-100 aircraft. Turbulence and high transient temperatures were also simulated by flying into the wing-tip vortex and engine exhaust from a KC-135 aircraft. Altitude for these missions was 35,000 to 40,000 feet, and airspeed varied between Mach .65 and Mach .85 (lower airspeeds were used to obtain higher vortex velocities). Test aircraft configuration for the first mission was clean. External tanks were installed for the second turbulence flight. Although the turbulence encountered was very severe, resulting in unusual flight attitudes, no compressor stalls were induced on either mission. These two flights indicated that turbulence is not the primary factor of the reported F-102 flameouts.

Ice-Crystal Environment

15. The remaining test missions were flown behind the KC-135 tanker aircraft in an artificially created ice-crystal environment. Since the ice-crystal concentration is inversely proportional to the distance flown behind the tanker, the closer the F-102A was to the KC-135, the greater was the ice-crystal intensity. F-102A performance in a known ice-crystal concentration was compared with that of other century-series fighters and other types of aircraft equipped with J-57 engines. In ice-crystal concentrations as low as 2.0 gm/cubic meter, the F-102A was the only aircraft tested that experienced compressor stalls. Figure 3 shows the F-102A in the simulated ice-crystal environment at 40,000 feet altitude. Table 1 gives a comparison between the various aircraft.

TABLE 1

AIRCRAFT PERFORMANCE IN A SIMULATED ICE-CRYSTAL ENVIRONMENT

				Engine Stalls At:	
Acft	Engine	Alt	Airspeed	Distance Behind Spray Nozzle	Ice Crystal Content (Approx)
F-100	J-57-P21	40M	M.85	400'	7 gm/m^3
F-101	J-57-P13	40M	M.85	400'	7 gm/m^3
F-102A	J-57-P23	40M	M.85	750'	2 gm/m^3
F-106	J-75-P9	40M	M.85	200'	20-25 gm/m^3
KC-135	J-57-P59W	40M	M.85	400'	7 gm/m^3

16. Further investigation was made to determine the effect of ice-crystal ingestion on engine operation when bleed air was removed from the compressor section. For this portion of the test, the F-102A compressor bleed valve actuation system was modified by installing two pneumatic solenoid valves to permit manual operation of the compressor bleed valve. The compressor bleed-valve actuation system on the KC-135 was disconnected to permit testing with the bleed valve open. The F-100 was not tested with the bleed valve open. Compressor bleed air, removed by actuating the anti-ice system, was sufficient to give improved engine performance in the ice-crystal spray. Removing bleed air from the compressor section did not improve F-102A performance, however, the KC-135 and F-100 engine stall margin and flameout margin were improved. Tables 1 and 2 indicate that the F-102A engine/duct configuration is more susceptible to compressor stalls than any other aircraft tested.

TABLE 2

AIRCRAFT PERFORMANCE WITHOUT COMPRESSOR BLEED AIR IN A SIMULATED ICE-CRYSTAL ENVIRONMENT

Acft	Anti-Ice	Compressor Bleed Valve	Alt	Airspeed	Engine Stalls At: Distance	Ice Crystal Content (Approx)
F-100	On	Closed	40M	M.85	250'	15-20 gm/m^3
KC-135	On	Open	40M	M.85	250'	15-20 gm/m^3
F-102A	On	Open	40M	M.35	750'	2 gm/m^3

17. Since the F-100, F-101, and F-102A carry the same basic J-57 engine (differing only in accessory location and afterburner units) the F-102A compressor stall problem may be one of ducting rather than one of engine or fuel control. This seems reasonable since the F-102A is the only test aircraft which developed flameout and compressor stall problems.

18. The F-102A ducting not only increases the engine operating problem in an ice-crystal environment but also increases the pilot's awareness of the problem. By virtue of the inlet duct location, the noise and vibrations associated with these transient engine disturbances are greatly magnified in the cockpit. The F-101, by contrast, has the inlet ducts located several feet aft of the cockpit and can sustain the same severity of engine surges but with much less noise and vibration noticeable in the cockpit.

19. A mission flown at 35,000 feet altitude and Mach .85 indicated the F-102A engine stall susceptibility was approximately the same as at 40,000 feet altitude. Two of the eight ice-crystal missions were flown with wing tanks. Engine stalls were experienced at an ice-crystal concentration of 2 gm/m^3 with or without wing tanks. The wing tank installation in no way affected the severity of the stalls.

20. F-102A engine operation was next checked at closer distances behind the tanker for higher ice-crystal concentrations. As the distances were decreased to 500 feet, an increase in the intensity of compressor stalls was noticed with corresponding instrument fluctuations. Engine RPM drops to 80 percent and fuel-flow drops to less than 1000 pph were common. The number of stalls per unit of time also increased at the 500-foot range. Decreasing the distance to 200 feet further increased the compressor stall intensity.

21. F-102A power requirement to maintain position in the spray at .85 Mach was approximately 92 percent rpm. Rapid throttle movements were made and the afterburner was cut in and out; no change occurred in the engine stall pattern.

22. No F-102A flameouts were induced because the resulting power loss was simultaneous with the compressor stalls, and the test aircraft would drop out of the spray before flameout. Also tested for both compressor stalls and flameouts were the KC-135 and the F-106 engines (Table 3).

TABLE 3

AIRCRAFT PERFORMANCE IN AN "INCREASED" ICE-CRYSTAL CONCENTRATION

Acft	Anti-Ice	Compressor Bleed Valve	Alt	Airspeed	Engine Stall Distance and Ice-Crystal Content		Engine Flameout Distance and Ice-Crystal Content	
KC-135	Off	Closed	40M	M.85	400'	7 gm/m^3	250'	15-20 gm/m^3
KC-135	On	Open	40M	M.85	250'	15-20 gm/m^3	100'	45 gm/m^3
F-106	Auto	Closed	40M	M.85	200'	27 gm/m^3	175'	35 gm/m^3

23. Although the test F-102A was equipped with continuous ignition (i.e., normal ignition operating continuously) no evaluation was made because flameouts were difficult to induce. The KC-135, used to test the J-57-P59W engine, incorporated a continuous ignition system which was separate from the normal two ignitor, 20-joule engine ignition systems. The test ignition system installed on the Nr 2 engine supplied one joule of energy to one ignitor only. Since the test engine of the KC-135 could be held in the spray a sufficient length of time to induce flameouts, the 1-joule continuous ignition system was tested for relight capabilities. Results of this test indicated reliable engine relight capability with low energy continuous ignition following flameouts (up to 12 seconds duration) resulting from ice-crystal ingestion at 40,000 feet altitude and at speeds of Mach .80 to Mach .85. Previous continuous ignition tests substantiate the relight capabilities of low-energy continuous ignition under various adverse weather conditions (WADD Reports WCT Nr 59-37, 59-24, 59-34, 59-62).

24. No record was made of the number of individual F-102A compressor stalls induced but 300 is a conservative estimate. Series of 30 or more stalls in succession were not uncommon. The KC-135 used in this test was also subjected to approximately 200 severe compressor stalls, and numerous compressor stalls were induced in the F-100, F-101, and F-106 aircraft. No engine damage resulted from the induced compressor stalls.

PROJECT ROUGH RIDER

Flight Preparation

25. All "Rough Rider" flights were preceded by a discussion of overall mission requirements and detailed weather briefings. The specific work area was selected while the storms were but small specks on the radarscope, assuring timely arrival of the project aircraft at the test location at the approximate time that the storms reached

maturity. Airspeed, altitude, outside air temperature, engine pressure ratio, percent RPM, EGT, fuel flow, and aircraft attitude, were recorded and shown on a photo panel. During aircraft penetrations, engine compressor inlet pressure P_{t_2}, compressor discharge pressure P_{t_4}, normal acceleration, pitch roll and yaw rates, were recorded by an oscillograph.

26. Prior to each F-102A penetration, a T-33 aircraft entered the storm to check for any damaging hail. If no hail was present, the F-102A followed very shortly thereafter on the same heading and altitude. If possible, the F-102A was directed to the area of brightest return on the radarscope, i.e., the area of densest precipitation. A variety of storm conditions were penetrated with the aid of radar. A sample flight, graphic illustrations of radarscope recordings, a summary of flight conditions, and the pilot's comments, are presented in the data section (Tables B2, Figures B5, and B6, of Appendix B).

Thunderstorm Characteristics

27. Experience has shown that most thunderstorms have a horizontal cross-section as shown in Figure 6. The greatest turbulence in these storms was found in the core (or area of greatest precipitation). Project pilots could only describe the precipitation in this area as "slushy moisture." It was probably a mixture of ice crystals, light rain or freezing rain, and soft hail. Hail was encountered mostly in the core, but was found many times downwind of the core. (During one penetration, radar returns indicated development of a tornado about 10 miles from the flight path of the aircraft. Tornadoes were quite common during this season of the year and every precaution was taken to avoid them.)

28. Another part of the storm that caused concern was the relatively non-turbulent anvil and cirrus overhang on the downwind side of the storm. This area contained heavy ice-crystal concentrations. It appeared on the radarscope as a light, snowy area; the scope gain had to be turned up quite high to get a definite outline of it.

Stall Patterns

29. Aircraft reactions may best be examined from oscillograph tracings taken during a typical storm penetration (Figures B2, B3, and B4). For Pass Nr 2, Figure B2, direction of flight was easterly and progressed from the upwind side of the storm through the hard core, the heavy precipitation and turbulence area, and then downwind through a well-developed ice-crystal area. Flight time in the storm on this particular pass was six minutes. The 241 compressor stalls experienced on this pass are very representative of the kind of stall patterns to be expected in a thunderstorm, and prove definitely which part of the storm produces the most dangerous stalls.

30. Figure B2 shows airplane and engine reactions in the storm's hard core. These oscillograph recordings show clearly the large changes in roll attitude and accelerations up to about 2 g's. Changes in yaw and pitch were negligible. Compressor stalls were spaced about one every two seconds. Notice the compressor discharge pressure (P_{t_4}) for this part of the pass. After each stall, this pressure recovered to its original value rather slowly, making the slope of the pressure recovery curve nearly horizontal. Also, the engine RPM hovered around 83 to 84 percent and the exhaust gas temperature was relatively low.

31. As the aircraft proceeded out of the hard core into the anvil (or ice-crystal area), the compressor stalls became much stronger and closer together, substantiating earlier test results, which had indicated that ice crystals cause compressor stalls. However, the P_{t_4} recovery rate in this area was much improved; engine RPM's remained above 85 percent and the EGT ran at a much more comfortable level.

32. The stall pattern described in the previous two paragraphs was repeated on many other passes. Thus, the heaviest stalls occurred in the relatively non-turbulent high ice-crystal-content anvil. Of more concern were those stalls which were encountered closer to the hard core of the storm where compressor pressure recovery performance deteriorated. Stalls occurring in the hard core on Flight Nr 5 as shown in Figure B2 were spaced sufficiently far apart so that engine RPM's did not drop below 83 percent. But, compared to similar conditions experienced on Flight Nr 12 and shown in Figure B4, the stalls of Pass Nr 7 were much closer together, and since the pressure recovery was poor, the RPM's dropped below 80 percent. Eventually the stalls ceased and the engine recovered. On Pass Nr 8, the stall pattern was the same as on Pass Nr 7, except that the stalls continued in this extreme condition until the engine flamed out. At this point, the pilot closed the throttle and restarted the engine at a more favorable altitude and airspeed.

CONCLUSIONS

33. The experience of many thunderstorm penetrations has shown the kind of atmospheric conditions to be expected and the areas to be avoided for maximum mission capability of the F-102A. Extremely adverse engine operation was encountered in the thunderstorm's hard core, or area of brightest radar return, an area to be avoided if at all possible. The stall patterns experienced during Rough Rider proved that the hard core of a storm is its most dangerous part for F-102A operation. Other storm areas will be a lesser problem provided the pilot does not move the throttle during compressor stalls. The non-turbulent ice-crystal areas on the outer edges, and especially in the anvil, produce some rather frightening noises but do not greatly decrease engine performance. The best procedure always is to avoid the storm completely, if possible.

34. Test data (Appendix B) shows that continuous ignition proved most satisfactory at Oklahoma City. However, it is not a cure-all for the F-102A high-altitude compressor stall-flameout problem. A complete redesign of the F-102A intake duct system would be necessary to completely eliminate this problem. Continuous ignition is the most expedient solution to the present problem and it will provide adequate protection in almost all situations.

35. The flight handbook 220 KIAS best glide and best engine restart speed which is also recommended in the flight safety supplement was well proved in the tests. On Flight Nr 12, Pass Nr 8, after the flameout, in order to clear the storm center quickly, the pilot maintained the airspeed at least ?0 knots above the recommended 220 KIAS, and at times, was as high as 300 KTS. He was unable to restart the engine until he brought the airspeed down to 220 KTS. By this time he had tried three restarts and was close to 31,000 feet altitude.

RECOMMENDATIONS

36. Recommendations have already been submitted to the F-102 Engineering Office, SANEO, SAAMA, in letters dated 26 October 1959, 6 April, 12 October, and 28 October 1960. These recommendations were also made to the Commander ADC, Ent AFB, Colorado, in letters dated 30 August and 14 September 1960.

37. It was recommended that a simple electrical connection for continuous operation of the ignition system by means of a single switch on the pilot's panel be installed in all F-102 aircraft. (See Figure C-1.) The ignition system on the test aircraft has been operated in this manner for many hours with no malfunction.

38. It was recommended that when experiencing engine stalls during thunderstorm flight in the F-102, the pilot perform the following:

(1) Ignition button DEPRESS
Depress and hold the ignition button.

(2) Afterburner OFF

(3) Check engine instruments for engine mechanical failure and overtemperature.

(4) Do not retard throttle unless engine failure or overtemperature is evident. If overtemperature condition exists, retard throttle slowly to prevent exceeding EGT limits. During operation above 40,000 feet, avoid retarding throttle below 85 percent RPM.

(5) Maintain straight and level, unaccelerated flight until the engine stall condition is relieved. Compressor stalls may cause an appreciable loss of thrust or flameout. Maintain level flight provided airspeed is above 220 KIAS. If this is not possible maintain heading and establish best glide of 220 KIAS with gear up and speed brakes closed.

(6) If an overtemperature persists, fuel control switch to EMERGENCY.

(7) If EGT exceeds maximum acceleration limit, throttle to OFF. Retard throttle to OFF if above procedures do not keep EGT within maximum acceleration limits (refer to ENGINE OPERATING LIMITS, Section V).

(8) Make an air start
After stabilized condition is obtained, restart; refer to ENGINE AIR START in Section III.

(9) Make entry on Form 781
Record any compressor stall and indicate duration and peak temperatures of any overtemperature operation.

This information was provided for a Safety of Flight Supplement which has been prepared for inclusion in the F-102A flight handbook, and is presented in Appendix C.

APPENDIX A

TESTS IN SOUTH-CENTRAL OHIO

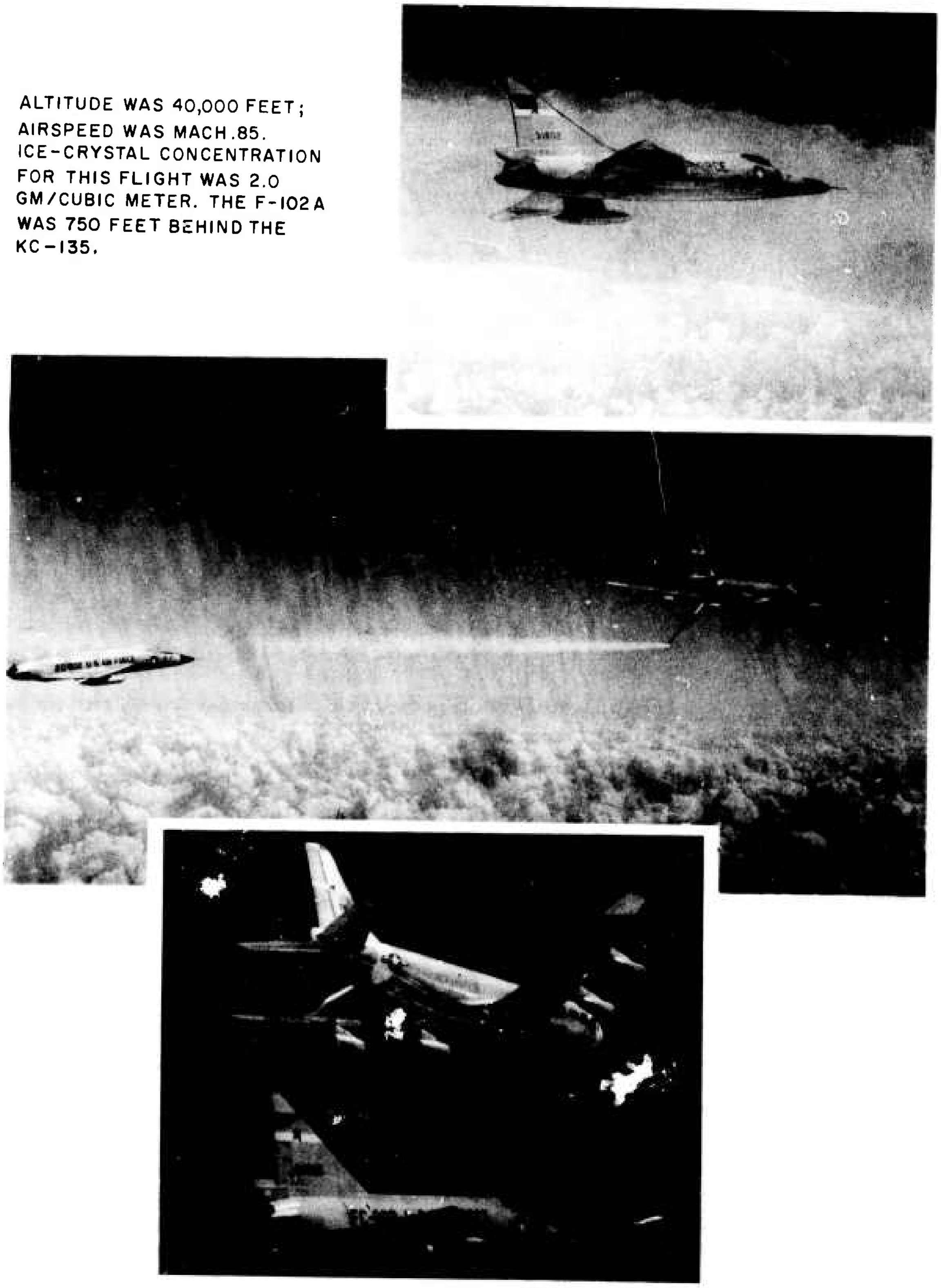


Figure A1. F-102A flight into the simulated ice-crystal environment created by a KC-135 aircraft in south-central Ohio.

APPENDIX B

TEST DATA FOR "ROUGH RIDER" FLIGHTS

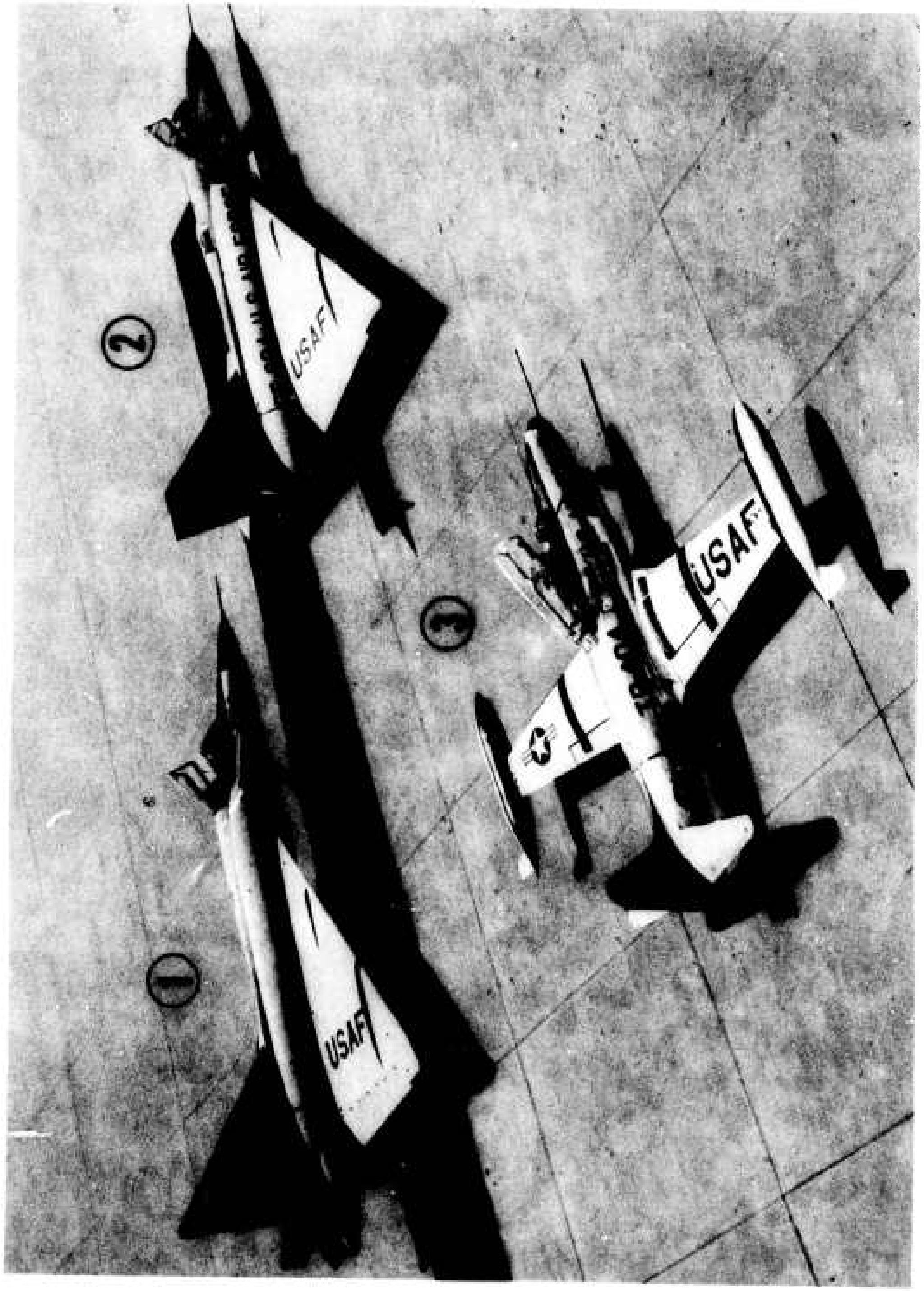
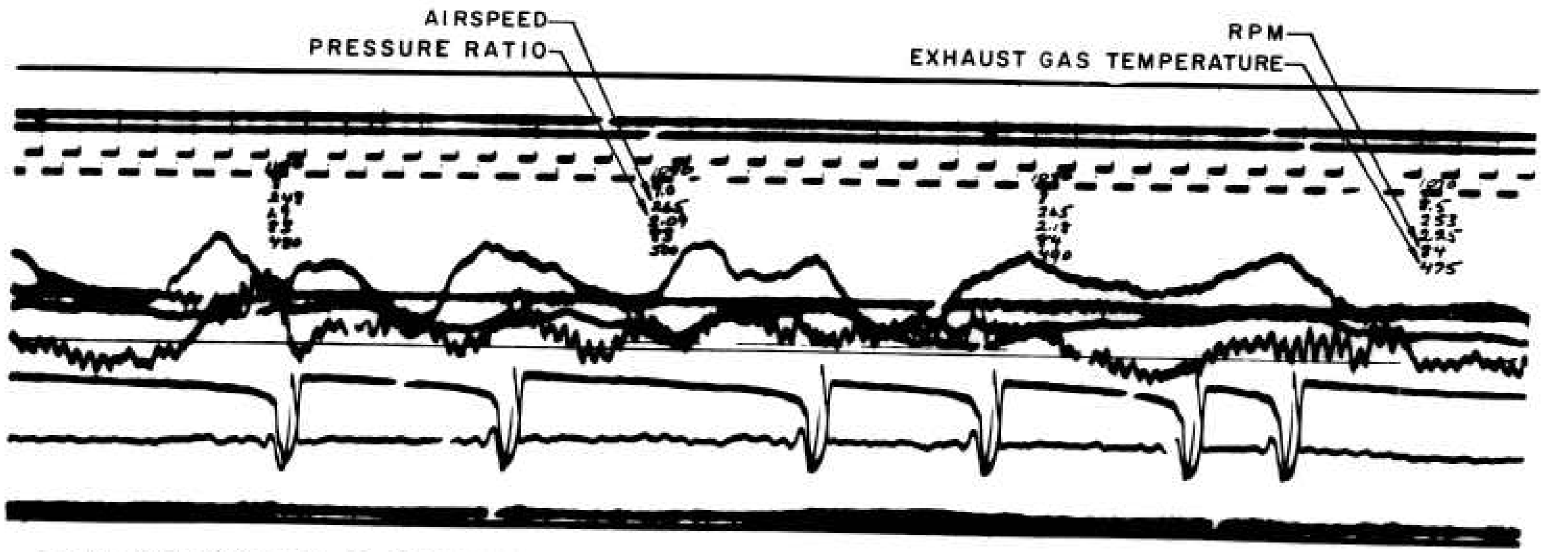


Figure B1. Aircraft used in high-altitude thunderstorm tests at Tinker AFB, Oklahoma: (1) F-102A, (2) F-106, and (3) a T-33 NASA research aircraft.

NOTE: THESE OSCILLOGRAPH RECORDS READ FROM RIGHT TO LEFT.



STALLS ENCOUNTERED AT BEGINNING OF PASS WHILE FLYING THROUGH HARD-CORE AREA OF STORM.

Figure B2. Oscillograph recordings of compressor stalls experienced during Pass Nr 2 of Flight Nr 5, Project "Rough Rider," 27 May 1960. (A total of 241 compressor stalls were encountered on this pass.)

NOTE: THESE OSCILLOGRAPH RECORDS READ FROM RIGHT TO LEFT; THE RIGHT OF THIS TRACE JOINS THE LEFT OF AND STARTS 140 SECONDS AFTER THE TRACE ON THE PREVIOUS PAGE.

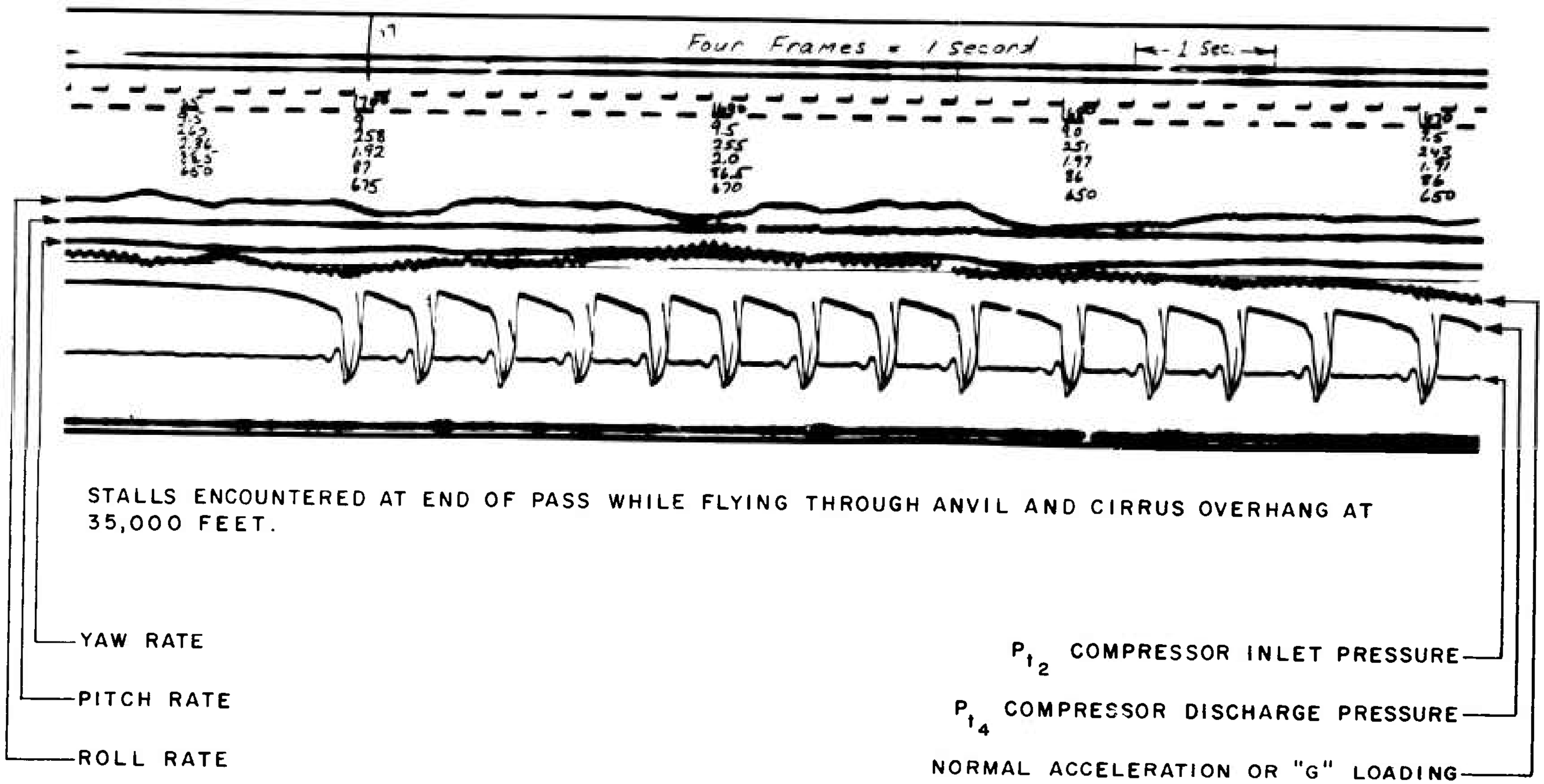


Figure B2. (Continued)

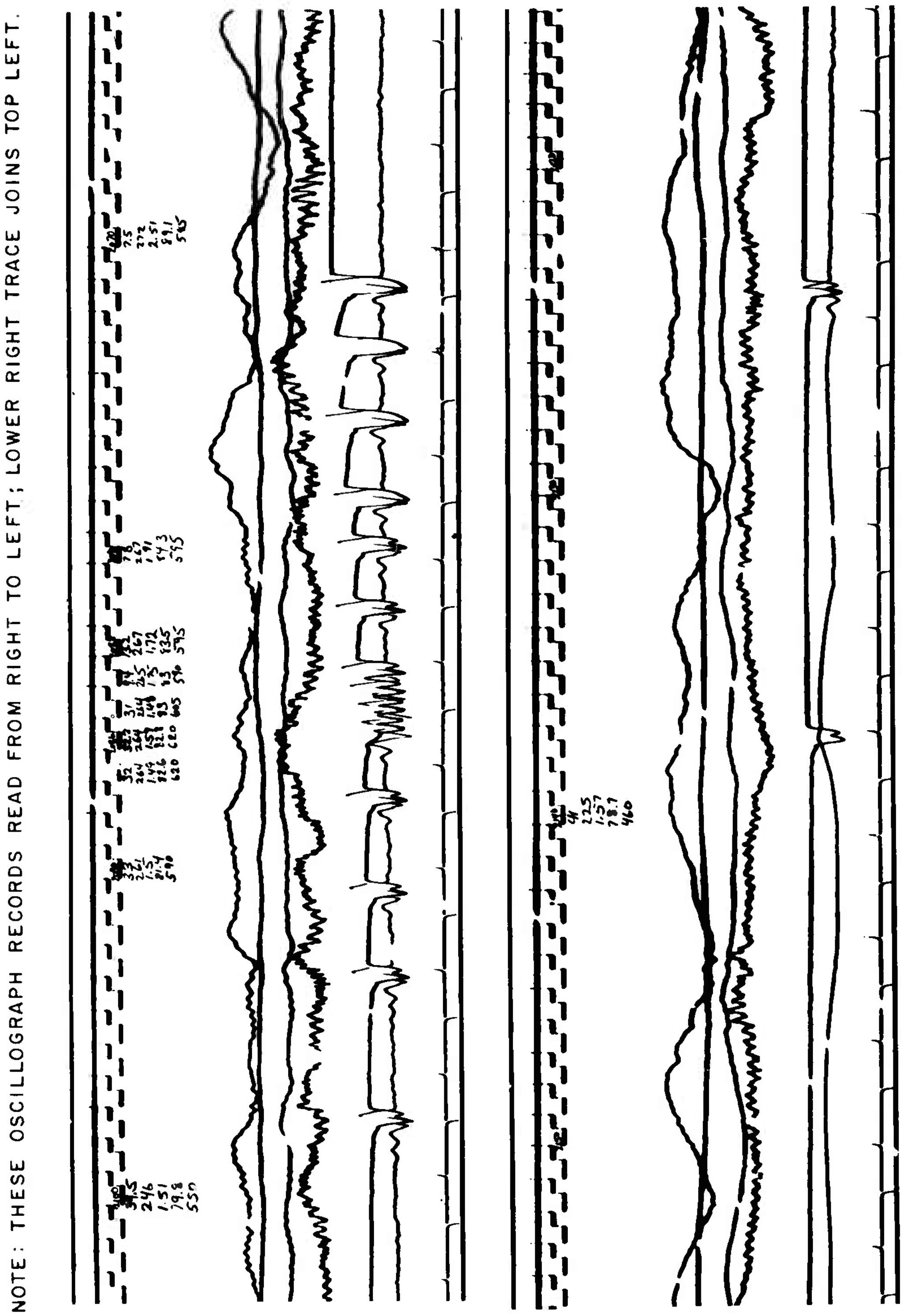


Figure B3. Oscillograph recordings of compressor stalls experienced during Pass Nr 7 of Flight Nr 12, Project "Rough Rider," 27 May 1960.

NOTE: THESE OSCILLOGRAPH RECORDS READ FROM RIGHT TO LEFT; LOWER RIGHT TRACE JOINS TOP LEFT.

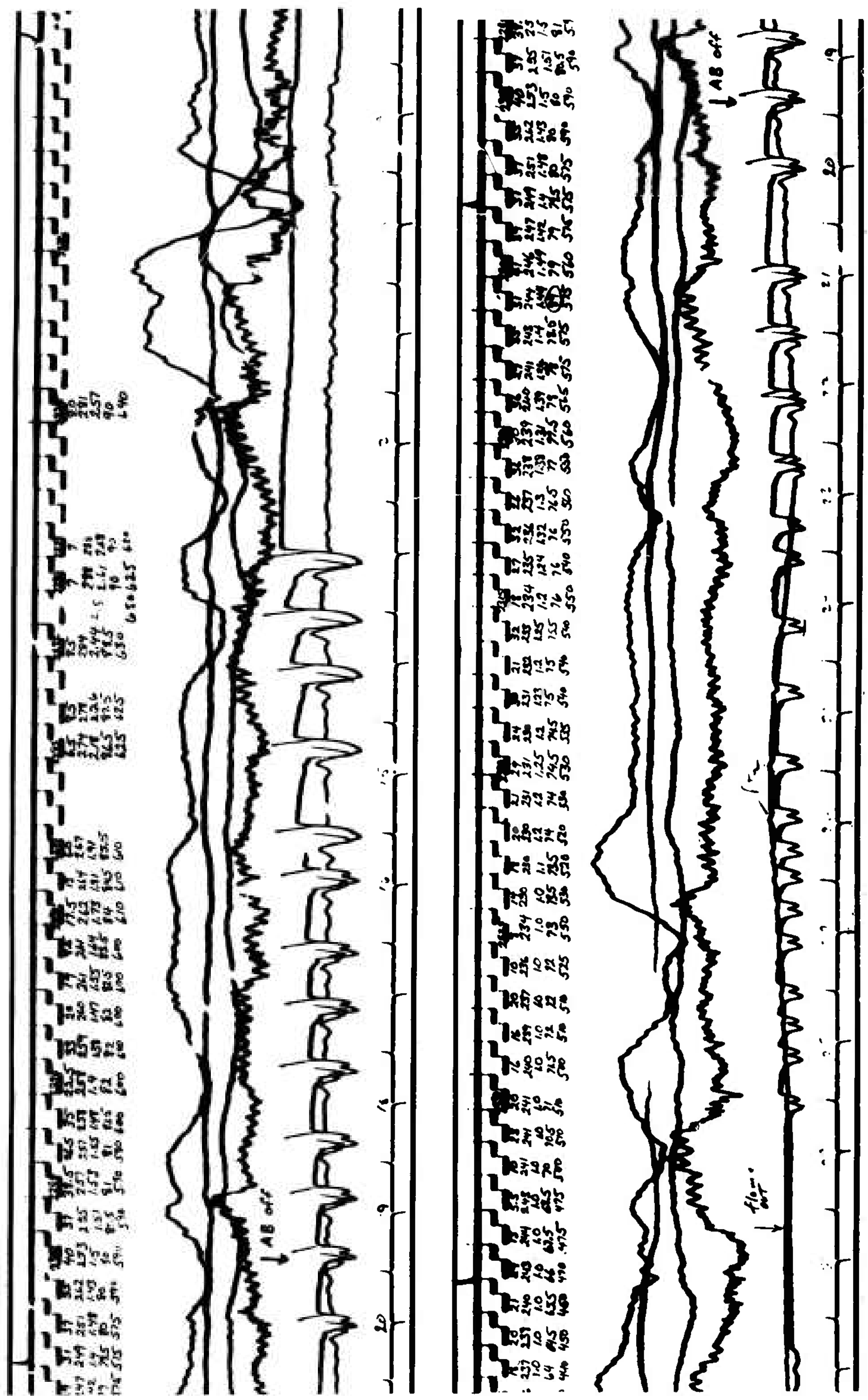


Figure B4. Oscillograph recordings of compressor stalls experienced during Pass Nr 8 of Flight Nr 12, Project "Rough Rider," 27 May 1960.

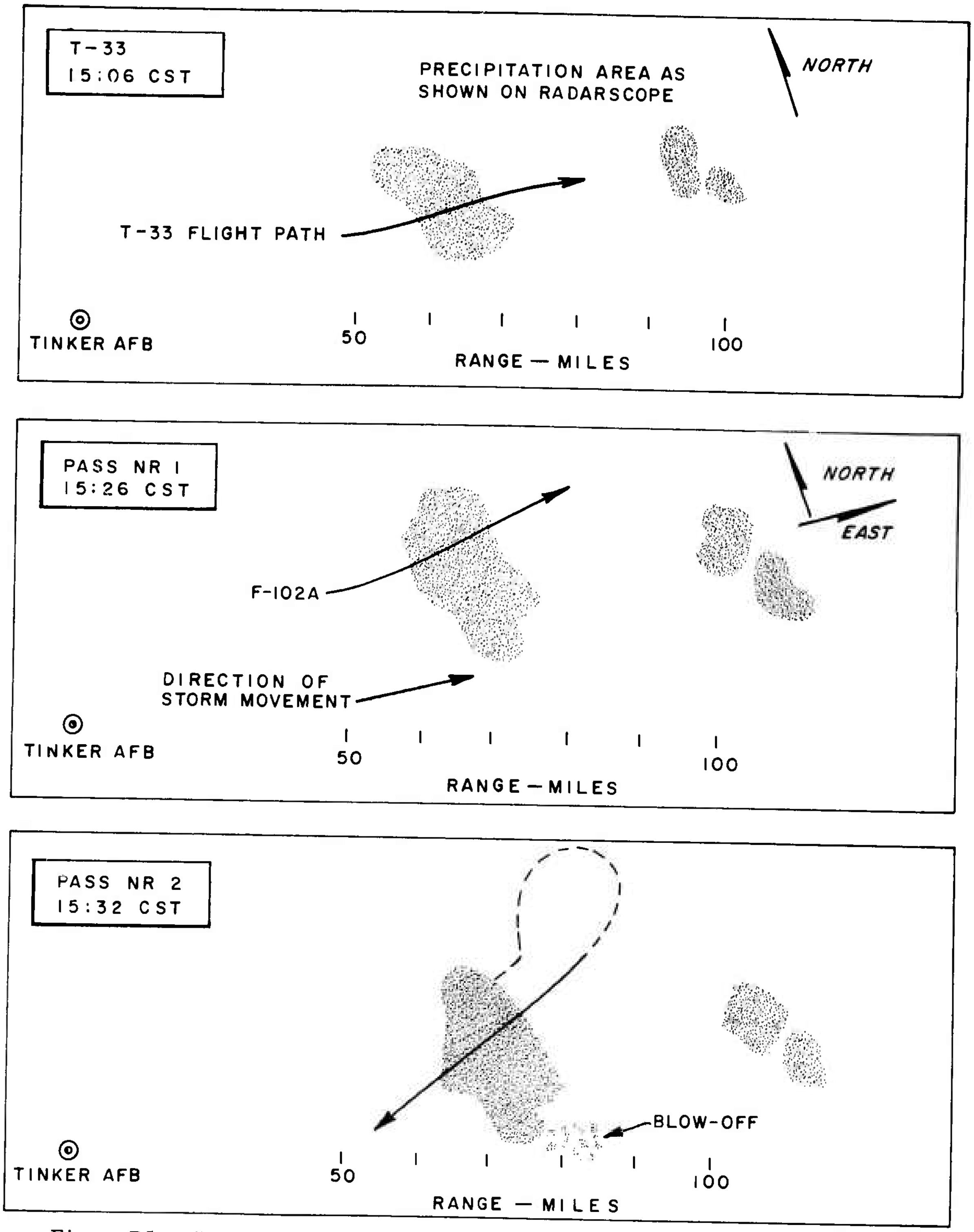


Figure B5. Graphic presentation of F-102A thunderstorm penetrations, Project "Rough Rider," 27 May 1960. (The first illustration shows storm penetration by the NASA T-33 prior to penetrations by the F-102A. If hail had been encountered, the F-102A would not have entered this particular storm.)

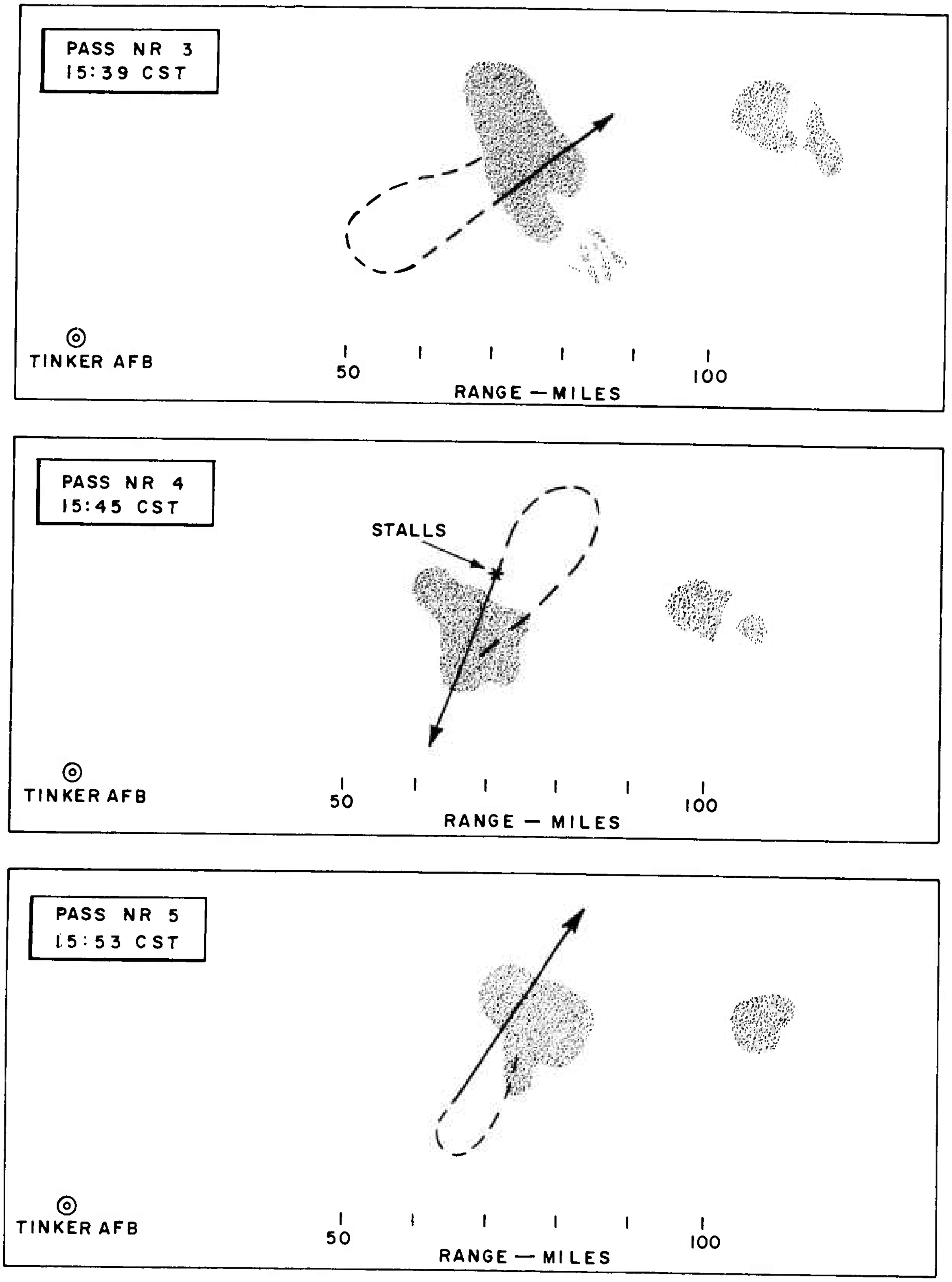


Figure B5. (Continued)

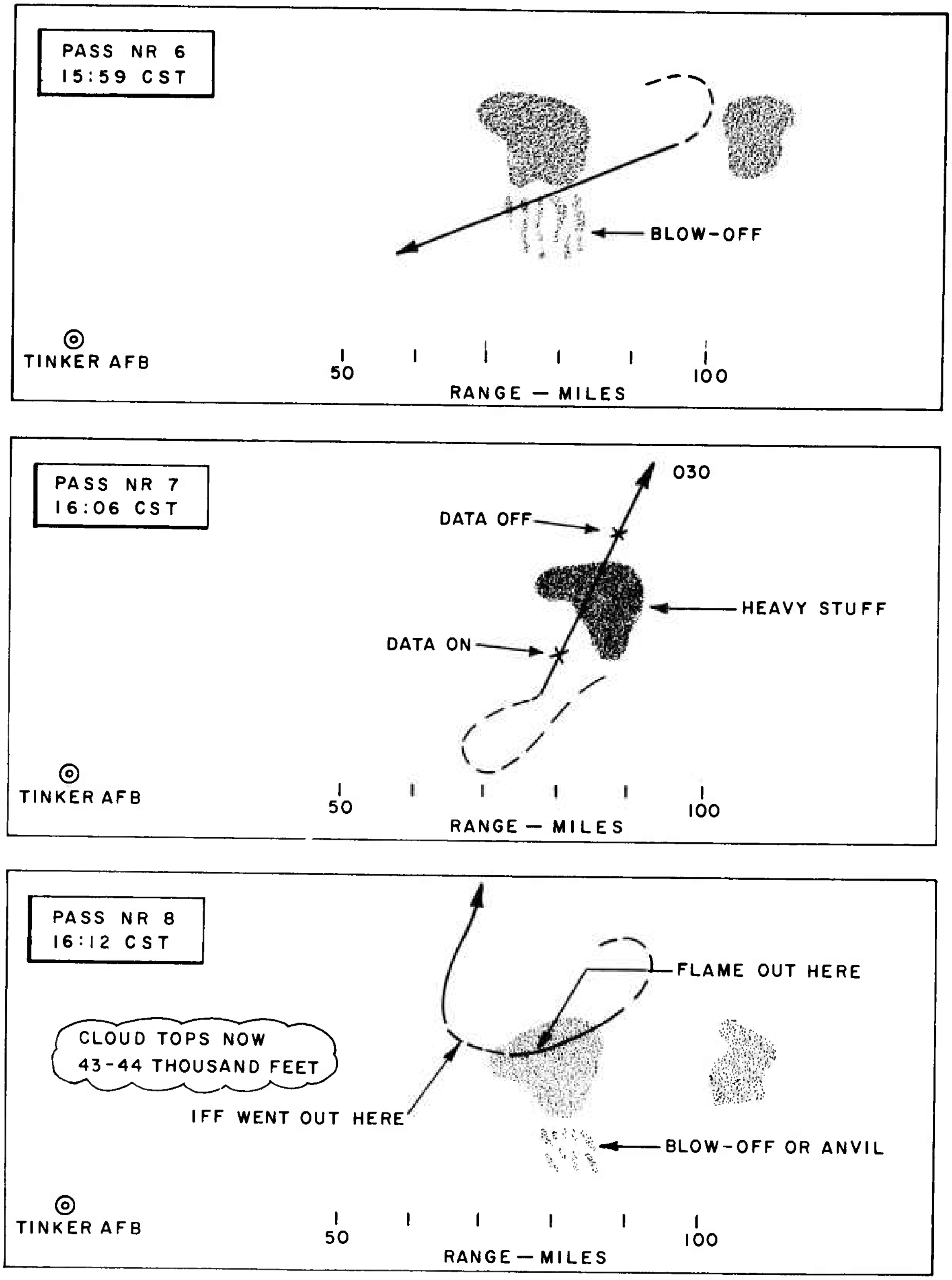


Figure B5. (Continued)

A typical F-102A flight - 27 May 1960:

The storm was located ENE of Tinker AFB about 60 miles. The storm cell was isolated and well-defined on the radarscope. Cloud tops were estimated to be as high as 44,000 feet. The test aircraft were off at 14:30 CST. The F-102's mission was to make as many penetrations of the storm cell as data time would permit. Pilots reported that the storm was well-defined on the northwest or upwind side, and was obscured in a cirrus shelf or cap on the downwind side. At 15:06 the F-102A made its first storm penetration. A copy of the radar presentation for each pass is reproduced here, along with a summary of the storm and flight conditions encountered by the pilot.

Pass Nr 1

15:26 CST - The aircraft made the first penetration on a heading of 070° at 38,000 feet. Just before entry into the cloud the pilot reported cloud tops to be at 41,000 feet. Light to moderate turbulence going briefly to heavy was experienced. The pilot was on instruments in the cirrus overhang on the lee side of the cloud during his turn around in preparation for run nr 2. No compressor stalls were experienced.

Pass Nr 2

15:32 - Heading 230° at 35,000 feet. Heavy turbulence, some moisture but no hail. No compressor stalls.

Pass Nr 3

15:39 - Heading 050° at 36,000 feet. Headed in direction where the cloud is bubbling up the highest. Very light turbulence and no moisture. No compressor stalls.

Pass Nr 4

15:45 - Heading 210° at 38,000 feet. Experienced moderate turbulence and some moisture. After four stalls the airspeed dropped off 40 knots. RPM hung up at 78 percent for a while and then gradually increased to 79 percent. Fuel flow was stuck at 1500 PPH, EGT 400°, EPR 1.75. The aircraft broke out of the storm at 36,000 ft and engine recovery from this point was good. 23 stalls were experienced. They were not as strong as previous stalls but were spaced close together causing a rapid loss of EPR and RPM.

Pass Nr 5

15:53 - Heading 030° at 37,000 feet. Moderate turbulence, no moisture, no stalls.

Pass Nr 6

15:59 - Heading 250° at 35,000 feet through blow-off area (anvil) on southeast side of storm. Very little turbulence, no moisture, no stalls. Aircraft was a bit too high; above main part of cloud.

Pass Nr 7

16:06 - Heading 020° at 40,000 feet. The aircraft first entered light cirrus, broke into a clear area of several miles and then hit the main storm cloud hard. Encountered heavy turbulence, precipitation and lightning. Many stalls occurred in a row, as many as eight or ten in two seconds. The engine was hung for a long time at 79 percent before recovering.

Pass Nr 8

16:12 - Heading 250° at 40,000 feet. Cloud tops appeared to be at 44,000 feet. AB was on and speed brakes out to keep the aircraft subsonic. More turbulence and precipitation. More stalls similar to those encountered in run nr 7. The afterburner was turned off and shortly thereafter, the engine flamed out. A restart was made at 30,000 feet.

TABLE B1

SUMMARY OF IMPORTANT F-102A THUNDERSTORM PENETRATION DATA OF EACH PASS SHOWN IN FIGURE B5

PASS NR	ACFT PENETRATION TIME	HEADING (degrees)	ALTITUDE (ft)	CLOUD TOPS (ft)	TURBULENCE	MOISTURE	HAIL	ENGINE STALLS
1	15:26	070	38,000	41,000	light to-heavy (briefly)			none
2	15:32	230	35,000		heavy	some	none	none
3	15:39	050	36,000		light	none	none	none
4	15:45	210	38,000		moderate	some		23
5	15:53	030	37,000		moderate	none		none
6	15:59	250	35,000		very little	none		none
7	16:06	020	40,000		heavy	heavy with lightning		as many as 8 or 10 in 2 seconds
8	16:12 (FLAMEOUT)	250	40,000	44,000	heavy	heavy		as many as 8 or 10 in 2 seconds

RADARSCOPE READING AT 15:25 CST

RADARSCOPE READING AT 15:50 CST

Figure B6. Radarscope presentation taken during F-102A flight test operations, Project "Rough Rider," 27 May 1960. Penetration area was an isolated cell of a thunderstorm located 85° and 60 miles from Tinker AFB, Oklahoma. (Notice "blow-off" or ice-crystal formations on the SE side of clouds in the NW quadrant.)

FLIGHT PILOT COMMENT
(Flight of 27 May 1960)

AFTER THUNDERSTORM PENETRATION

"Turbulence in this storm as experienced by all test aircraft was milder than that encountered on previous flights. Aircraft roll rates were considerably reduced. Precipitation also was much lighter than on previous flights. A quick examination of the aircraft showed that a small amount of hail had been encountered. There were some very small dents on the intake ducts and wing fences.

"No stalls occurred on passes which were outside of the precipitation area. Engine recovery rate after a series of stalls seemed to be very poor. This is a condition which gradually became evident on previous flights, and has really become serious on this flight. The engine would hang up for excessively long periods of time at any RPM below 80 to 85 percent."

DURING THUNDERSTORM PENETRATION

The following is a direct quotation from a transcript of pilot comment describing the flameout which occurred on Pass Nr 8 of "Rough Rider" flights near Tinker AFB, Oklahoma, 27 May 1960:

"On the last pass, I had the burner going, and with the speed brakes out to keep from going supersonic. In fact, I was playing with the speed brakes to try to maintain around .9 to .92 Mach number. Very shortly after entering the storm, through heavy clouds, the engine started stalling just as it had before with 'military' power. I was in turbulence and had experienced probably a half-dozen stalls or more when I pulled the throttle out of AB into military power. Shortly thereafter, the thing just flamed out. I continued on heading. When the RPM wound down to below 70 percent, I knew the thing had quit, so I pulled the throttle back to idle and then, while still in the storm, selected dual ignition rather than single, and just set up a glide to continue on out of the storm. Broke out about 36,500, as I recall, and the fire never did start again by using the continuous ignition switches. However, I feel sure this was due to the fact that the RPM was still a little bit too high. When the RPM finally stabilized between 25 and 30 percent, I 'stopcocked' the throttle and turned the ignition off for a few seconds; then made a normal air start using the ignition button on the throttle. The first time I attempted this at about 34,000, it didn't work, so I shut it off again. The second time, it fired at about 31,000. I feel quite sure it would have been impossible to 'deadstick' the thing due to the canopy's and windshield's icing over, which it does on every flight; so it was fortunate that we got the thing started."

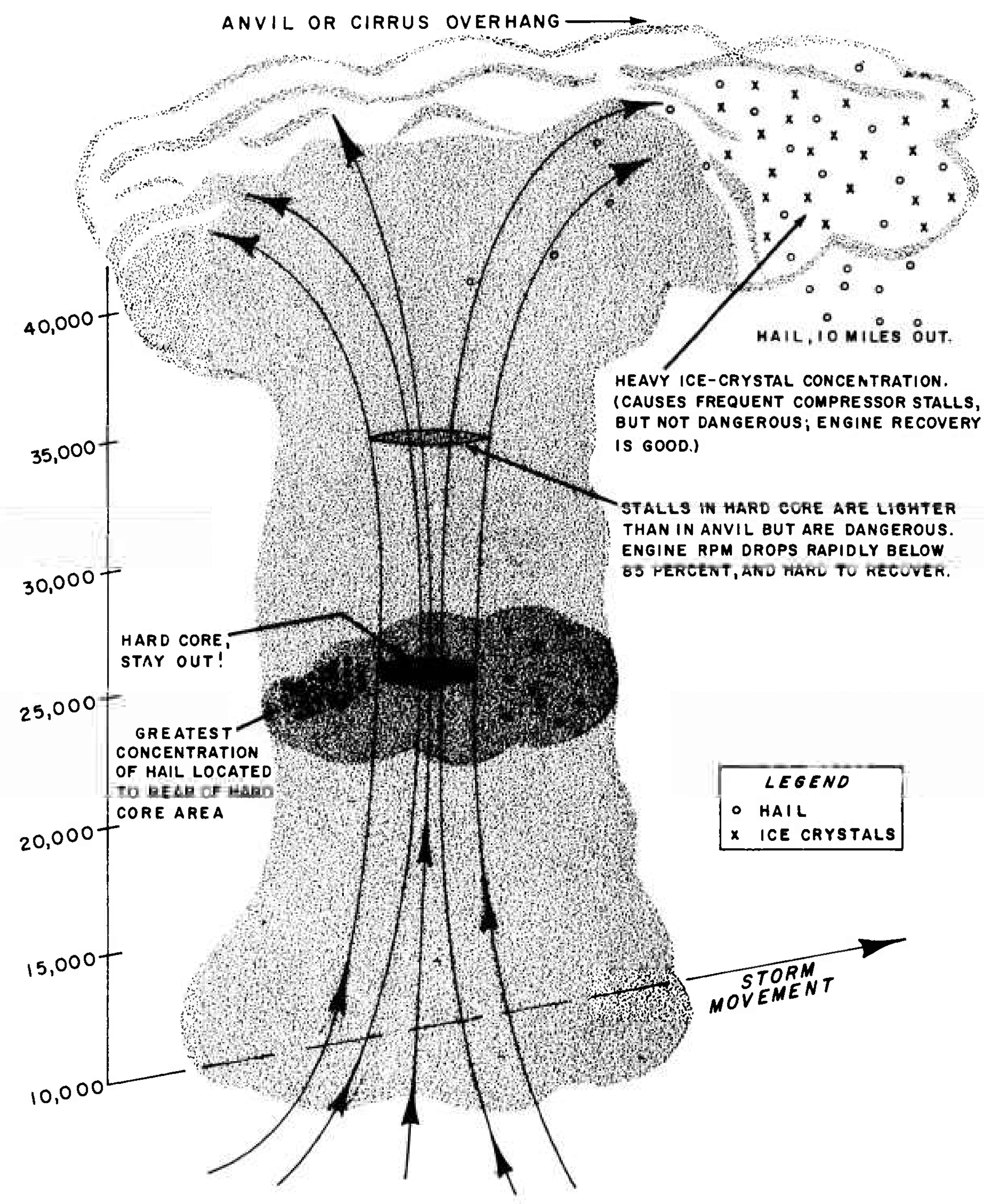


Figure B7. Thunderstorm cross-section, Project "Rough Rider," 27 May 1960.

TABLE B2

SUMMARY OF F-102A THUNDERSTORM PENETRATION DATA SHOWING FLIGHT PARAMETERS FOR PASSES ON WHICH STALLS OCCURRED, PROJECT "ROUGH RIDER"

Flight Nr	Run Nr	Time	Altitude	KIAS	EPR	(%) RPM	EGT	Data Time	Nr of Stalls	Total
5	1	1556 23	40,900	243	2.70	91	640	3:11	15	15
	Min	Values	39,000	243	2.0	83	640			
	Max	Values					500			
	2	1610 46	35,300	272	2.00	85	575	5:54	241	256
	Min		31,000	235	1.80	80	575			
	Max						675			
9	1	1424 11	40,500	270	2.5	90	625	1:32	11	267
	Min		39,500	250	1.80	80	625			
	Max						625			
	2									
10	1	1231 00	35,300	306	2.30	90	600	0:57		
	2	1241 02	30,400	274	2.10	88	525	3:15		
	3	1255 45	35,600	287	2.10	86	500	2:35		
11	1	1343 10	40,600	278	2.60	92	625	4:45	15	282
	Min		40,400	251	2.30	90	600			
	Max						650			
	2	1352 46	40,500	256	2.50	90	600	3:03	7	289
	Min		40,200	242	2.10	86	575			
	Max						625			
	3	1402 58	40,500	271	2.50	90	625	5:26	94	383
	Min		34,300	208	1.18	72	310			
	Max						625			
	4	1417 07	40,500	259	2.40	88	600	4:33	25	408
	Min		38,000	233	1.90	80	425			
	Max						600			
12	1	1526 00	38,300	285	2.325	90	575	1:50		
	2	1532 55	35,400	310	2.32	90	575	1:10		
	3	1539 25	36,500	285	2.22	88	555	1:45		
	4	1545 20	38,300	255	2.2	86	550	2:20	23	431
		Min	36,500	220	1.50	78	400			
		Max					550			

TABLE B2 (Cont'd)

SUMMARY OF F-102A THUNDERSTORM PENETRATION DATA SHOWING FLIGHT PARAMETERS FOR PASSES ON WHICH STALLS OCCURRED, PROJECT "ROUGH RIDER"

Flight Nr	Run Nr	Time	Altitude	KIAS	EPR	(%) RPM	EGT	Data Time	Nr of Stalls	Totals
	5	1553 40	37,200	271	2.35	88	570	1:37		
	6	1559 25	35,100	297	2.39	89	575	1:35		
	7	1606 10	40,200	256	2.41	89	620	1:55	18	449
		Min	40,100	225	1.40	78	430			
							620			
	8	1612 25	40,700	265	2.48	90	645	3:40	31	480
		Min	30,200	220	0	25	75			
							665			

APPENDIX C

RECOMMENDED MODIFICATIONS

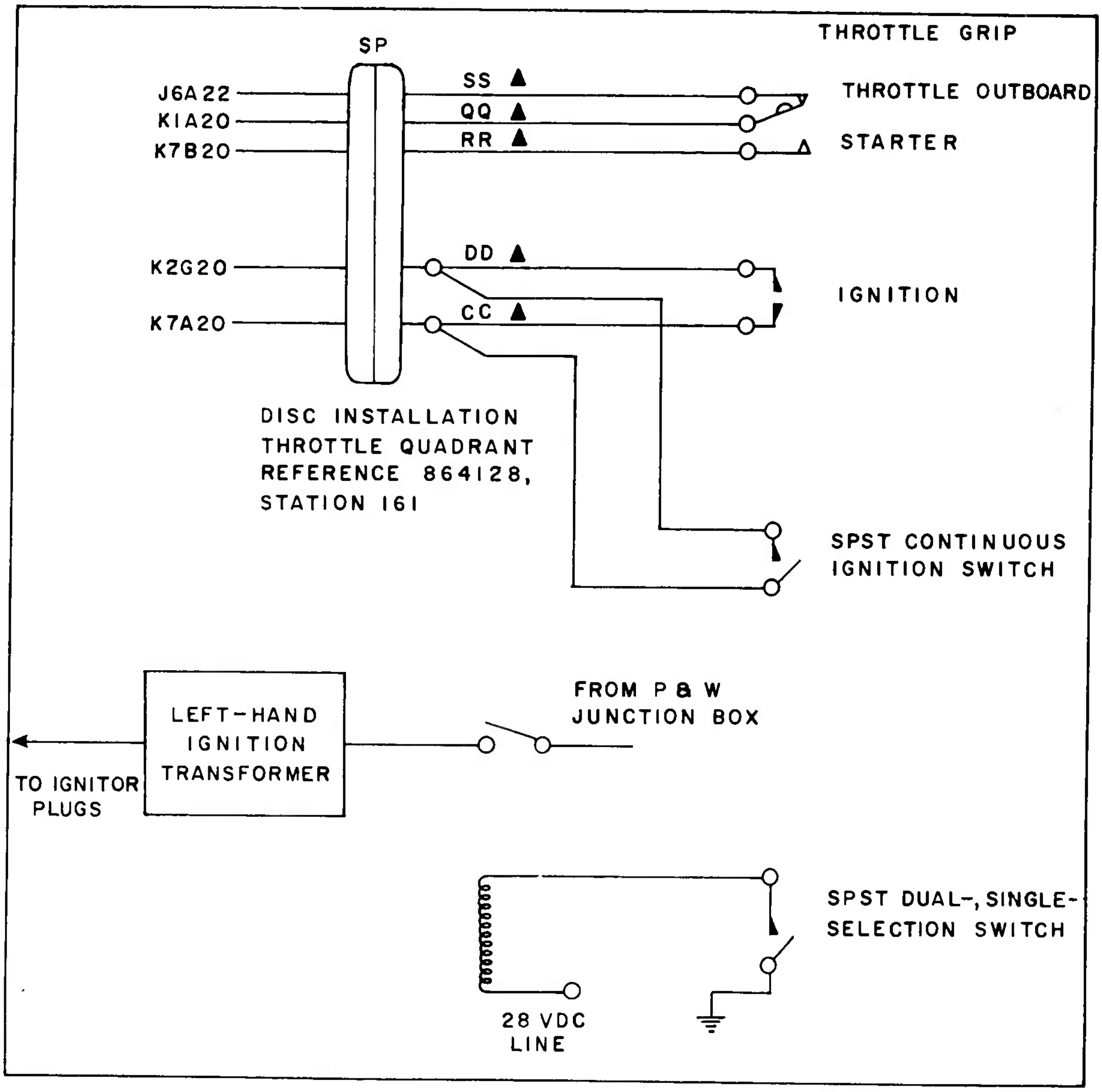


Figure C1. Recommended continuous ignition system, as used in the test aircraft for flights over Oklahoma City, Oklahoma, for installation in all F-102A aircraft. (The only alteration necessary to the present wiring system of the F-102's is the SPST switch installed in parallel across the pilot's push button switch, which is installed on the throttle. The extra switch is installed in a convenient location and relieves the pilot from having to hold the throttle button during each thunderstorm penetration. The relay shown at the bottom of the drawing was installed in the test aircraft to provide single- or dual-mode ignition. Only one side of the ignition system was used during actual tests, the other being left in reserve as a safety factor. This dual capability would not be necessary in the normal installation since the ignition system would not be subject to such long periods of use.)

SAFETY FLIGHT SUPPLEMENT FOR HANDBOOK F-102-1

GENERAL

Compressor stalls and flameouts may be experienced during normal operation at high altitude in areas of ice-crystal concentration such as found in or around clouds or thunderstorms. This type of compressor stall differs from clear-air compressor stalls primarily in the conditions under which they occur and the procedures to be followed. It is important that consideration be given to the type of compressor stall prior to taking action since the most effective corrective action will vary. If compressor stalls occur during pitch-up or zoom maneuvers, engine acceleration or deceleration, high altitude and low airspeed maneuvers, etc., the procedures outlined in Section III should be followed. However, if compressor stalls occur during operation at high altitude in or around clouds or thunderstorms, or in areas where precipitation from overhanging clouds may occur, the compressor stalls may be caused by ice particles or ice crystals. Compressor stalls due to ice-crystal ingestion may occur as individual loud reports or loud reports in machine-gun fashion. The compressor stalls are accompanied by airframe vibration and in some cases emission of vapor from the engine air intake ducts. During the machine-gun-type stalls, RPM drops to 80 percent or below, fuel flow drops to 800 PPH, and temporary loss of EPR occurs. When the individual stalls occur, RPM and fuel flow indicators fluctuate but return to normal. The procedures to be followed during compressor stalls due to ice-crystal ingestion differ from previous procedures in two main respects. First, the throttle should not be retarded as a standard procedure since retarding the throttle does not in any manner assist the engine to continue operation in an ice-crystal environment and may contribute to the stalled condition. Second, straight and level flight should be maintained, if possible, to prevent distortion of intake airflow by changes of pitch or yaw, which may further contribute to the stalled condition.

NOTE

> The main consideration during this type of stall is flameout, not engine damage. The engine can sustain hundreds of this type of stall without damage.

INSTRUCTIONS

The following instructions are applicable throughout the flight envelope of the aircraft and should be observed when operating in an ice-crystal environment

(1) Ignition button DEPRESS
(Depress and hold the ignition button)

(2) Afterburner OFF

(3) Check engine instruments for engine mechanical failure and overtemperature.

(4) Do not retard throttle unless engine failure or overtemperature is evident.

NOTE

If overtemperature condition exists, retard throttle slowly to prevent exceeding RGT limits. During operation above 40,000 feet, avoid retarding throttle below 85 percent RPM.

(5) Maintain straight and level, unaccelerated flight until the engine stall condition is relieved.

NOTE

Compressor stalls may cause an appreciable loss of thrust or flameout. Maintain level flight, provided airspeed is above 220 KIAS. If this is not possible, maintain heading and establish best glide of 220 KIAS with gear up and speed brakes closed.

(6) If an overtemperature persists, fuel control switch to EMERGENCY.

(7) If EGT exceeds maximum acceleration limit, throttle to OFF. Retard throttle to OFF if above procedures do not keep EGT within maximum acceleration limits (refer to ENGINE OPERATING LIMITS, Section V).

(8) Make an air start
After stabilized condition is obtained, restart; refer to ENGINE AIR START in Section III.

(9) Make entry on Form 781
Record any compressor stall and indicate duration and peak temperatures of any overtemperature operation.

Flight Test Division, Flight and Engineering Test Group, Wright Air Development Division, Wright-Patterson Air Force Base, Ohio.
F-102 HIGH-ALTITUDE FLAMEOUTS IN AND AROUND THUNDERSTORMS, by Philip I. Paul, 1st Lt, USAF. January 1961. 36p. incl. illus. Proj 201A(1) (WADD TN 60-296) Unclassified report.

It was determined that mixtures of ice crystals and other precipitation commonly found in the core of thunderstorms at high altitudes constitute an extreme operating hazard to F-102 aircraft. The hazard can be relieved to a large extent by the installa-

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tion and use of a continuous ignition system. It is recommended that the hard core or main precipitation area of the storm be avoided.

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