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USAFIFC TR 78-1



EVALUATION OF JET 2" STANDBY FLIGHT
INSTRUMENT SYSTEM

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FINAL REPORT

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Overall subject pilot performance on the 2" display was excellent, however, a higher level of effort and concentration was required to obtain desired performance on the display than the subject pilots normally expended on their primary instrument systems.

The attitude indicator, airspeed/mach indicator, and altimeter, are acceptable for installation in US Air Force aircraft with only minor cosmetic changes.

The directional gyro should not be installed in US Air Force aircraft until precession can be controlled during high dynamic flight and an additional evaluation can be accomplished. Some cosmetic changes are also required on this indicator.

PREFACE

This technical report presents the findings of Project TE 76-2 conducted by the USAF Instrument Flight Center, Research and Development Division (USAFIFC/RD) at the request of the Aeronautical Systems Division, Flight Instruments Division (ASD/ENAID).

Flying activities on the project were conducted at Randolph AFB TX. Human factors engineering support was provided by the USAFIFC/RD staff; systems engineering support was provided by Capt James P. Balma and Mr. George A. Rex, USAFIFC Aerospace Engineers; installation of project equipment was accomplished by Mr. Raoul Canamar and Mr. Orrin C. Kopff, USAFIFC Avionics Technicians.

This technical report has been reviewed and approved.



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INTRODUCTION

The USAF Instrument Flight Center, Research and Development Division (USAFIFC/RD) was requested by the Aeronautical Systems Division (ASD/ENAID) to conduct a pilot factors flight evaluation of the Jet Electronics and Technology, Inc. (JET) 2" Standby Flight Instrument System. This system consists of an airspeed/mach indicator, altimeter, directional gyro, and attitude indicator.

TEST OBJECTIVES

- a. To conduct a pilot factors evaluation using the JET 2" standby indicators as a set of standby/backup flight instruments.
- b. To identify any pilot factors related deficiencies of the JET 2" standby displays.

DESCRIPTION OF TEST ITEMS

a. Directional Gyro Indicator:

The JET Electronics Two-Inch Directional Gyro is a self-contained unit which eliminates the need for an additional remote directional gyro as a standby instrument. This produces a considerable savings in size and weight. The indicator is powered by 28V DC and is capable of driving a control transformer to provide azimuth information which is accurate to within $\pm 1.0^\circ$. A single knob provides the means of selecting the operating mode, either magnetic (slaved) or directional gyro (free), and of adjusting the heading indication. In the slaved mode, the maximum output error is $\pm 1.0^\circ$. In the directional gyro mode the gyro drift is 15° per hour or less. A power warning flag comes in view whenever power is interrupted.

b. Altimeter:

The altimeter is a counter-pointer display using a two-drum counter showing tens of thousands and thousands of feet. The pointer makes one revolution for each one thousand feet of altitude change. Change of the 1000 ft drum occurs over a 200 ft increment of altitude with motion of the drum commencing as the pointer passes the 800 ft mark with increasing altitude and the 0 ft mark with decreasing altitude. The barometric pressure counter indicates barometric pressure in inches of mercury. At negative altitudes, the ten thousand foot drum is red and white striped. The instrument has an internal vibrator to minimize friction. An internal potentiometer is provided to output barometric pressure to any aircraft subsystem requiring this information. Operating range of the altimeter is -1000 feet to +80,000 feet.

c. Airspeed/Mach Indicator:

The airspeed/mach indicator simultaneously displays indicated airspeed (IAS) and mach number with a single pointer. The pointer rotates as a function of the difference between total and static pressure.

The pointer sweeps across two concentric dials which are graduated logarithmically. A fixed airspeed dial is graduated in knots. A second moving dial is graduated in mach number and rotates as a function of static pressure. The operating ranges of the airspeed/mach indicator are:

50 to 800 knots indicated airspeed

0.5 to 2.2 Mach (at altitudes up to 80,000 feet)

d. Attitude Indicator:

The Attitude Indicator is specifically designed as a standby reference indicator for high performance aircraft. The system is self-contained and eliminates the need for additional electronic components. Self-contained compensations for turn and fore/aft accelerations are incorporated with manual caging for rapid realignment. In the event of complete electric power failure, approximately nine minutes of useful attitude information is presented as the gyro spins down. The unit uses 28V DC for the gyro, and 4V AC for lighting. Either red or white lighting is available. Attitude information is provided through 360° of roll and 90° of pitch with controlled precession.

TEST METHODOLOGY AND DATA COLLECTION

The 2" instruments were evaluated on local sorties from Randolph AFB. The test profile enabled the evaluation of the 2" instruments throughout the performance envelope of the NT-38 aircraft during both instrument and composite flight conditions.

Ten subjects, from the available pool of Instrument Flight Center (USAFIFC) pilots and students attending the USAF Instrument Pilot Instructor School, participated in this evaluation. Each subject flew three test sorties. The first sortie was flown using the standard T-38 instruments to familiarize the subject pilot with the profile and to obtain baseline performance data. The second sortie provided the first opportunity for the subject pilot to adapt to the new instruments and to integrate them into his instrument cross-check. On the third sortie, the subject pilot was required to fly all maneuvers on the 2" instruments.

Each subject pilot was given a briefing on the operation of the instruments prior to the first sortie. A check of the standby instruments was made during the instrument cockpit check on each sortie.

The flight profile consisted of the following hooded instrument maneuvers:

- (1) Climb
- (2) Level-off
- (3) Steep Turns
- (4) Unusual Attitude Recoveries
- (5) Penetration
- (6) PAR Approach
- (7) Missed Approach

The following maneuvers were flown unhooded:

- (1) Loop
- (2) Barrel Roll
- (3) Simulated air-to-ground attacks (4 patterns same direction)

During the high dynamic maneuvers, the subject pilot was requested to read out altitudes, airspeeds, headings, and dive angles during critical points in the maneuvers. If any misreadings occurred, it was noted by the project pilot. On the second and third sorties, the standard ADI, Altimeter, Airspeed Indicator, and Horizontal Situation Indicator were masked throughout the flights. On the first and third sorties, the subject's performance on each maneuver was rated by the project pilot. The same project pilot flew all three sorties with the same subject pilot. This gave a direct comparison of each subject's performance on the 2" Standby Instrument System versus the T-38's main instruments. On the third sortie, the subject pilot was provided with an inflight rating card and asked to rate the usability of the instruments after each maneuver performed. At the completion of the third sortie, each subject pilot was thoroughly debriefed by the project pilot using the post-flight interview card shown in attachment 3. Subjective pilot opinions and comments were recorded during each flight. Subject pilots were asked to openly comment on their impressions of the 2" standby system and the concept of a standby display.

RESULTS AND DISCUSSION

This evaluation has concluded that a particular group of subject pilots could satisfactorily perform a specific set of instrument maneuvers using this group of 2" standby instruments with a measurable increase in effort over the use of their normal instruments. This was, however, a controlled evaluation with the standby instrument package located in a very optimum and effective position in the test aircraft. This position facilitated the establishment of an effective new cross-check pattern in minimum time. Additionally, the subjects were allowed to concentrate maximum attention on the standby package as a result of the masking of the main instrument system. This situation eliminated the possibility of any conflict that might develop as a pilot attempted to establish a new instrument cross-check in the presence of a failed yet still visible primary instrument system.

Each 2" indicator will be discussed separately, first referencing the subject's performance, then by analyzing how the subjects rated the indicator's usability.

Attitude Indicator (AI):

During the loop, barrel roll and ground attack, the performance of all subject pilots was as good on the 2" AI as it was on the main ADI. During climbout, unusual attitude recoveries, penetration, and PAR, nine of ten subjects' performance was as accurate on the 2" AI as it was on the main ADI.

One subject pilot's performance dropped from excellent to satisfactory on the climbout, unusual attitudes, and penetration using the 2" instruments while on the PAR, another subject's performance decreased from satisfactory to marginal.

Ratings of the usability of the AI by the subjects ranged from excellent to unsatisfactory. Seven of ten subjects' usability ratings were satisfactory while only one subject rated the usability as unsatisfactory. This rating occurred on the PAR. Comments on the PAR indicated that precise pitch control was difficult due to the smallness of the indicator. Additionally, maintaining wings level was difficult due to the absence of a bank pointer at the top of the indicator. Steep turns had the lowest usability ratings due to the pitch precession encountered during these maneuvers. Seven of the ten subjects commented that due to the significant precession encountered, the performance instruments required a much more frequent than normal cross-check to achieve desired performance. Subjects also commented that while performing dynamic maneuvers with high dive angles (sixty degrees or more), pitch angles were difficult to read. Overall, subjects were able to perform all maneuvers satisfactorily on the AI but their usability ratings of the instrument were somewhat low.

The subject pilots' comments regarding their lower usability ratings were generally the result of increased workload with the 2" instruments to attain a satisfactory performance.

Airspeed/Mach Indicator:

Overall, the airspeed/mach indicator was found to be excellent. During all the maneuvers except climbout, ground attack, and PAR, the subjects' performance was the same on the 2" airspeed indicator as on the main airspeed indicator. During ground attack maneuvers, one subject's performance dropped from excellent on the main airspeed indicator to satisfactory on the corresponding 2" instrument. While flying the PAR and during climbout, another subject's performance dropped from satisfactory on the main airspeed indicator to a marginal on the 2" airspeed indicator. Subject pilots' ratings of the usability of the indicator ranged from excellent to marginal. Six of ten subjects rated the usability of the 2" airspeed indicator as satisfactory. Only on the climbout and the PAR maneuvers did the 2" airspeed indicator receive usability ratings of marginal. Seven of ten pilots stated that an adjustable airspeed reference marker was required in order to maintain precise airspeed control on instrument approaches. Three pilots commented that placement of the number "3" next to the three hundred knot tick mark, vice over it, caused a ten knot error in reading the airspeed. Most subjects found that small (one to two knot changes) were almost impossible to perceive. Also, it was commented that a dot in front of the mach number would be easier to read instead of the small circle currently present.

Altimeter:

Overall, the subjects' performance on the 2" altimeter were excellent. On unusual attitudes, loop, ground attack, and penetration, the subjects' performance was as accurate on the 2" altimeter as it was on the main altimeter. The performance of two subject pilots on the climbout and on steep turns dropped from excellent on the main altimeter to a satisfactory on the 2" instrument. On the barrel roll and PAR, another subject's performance dropped from satisfactory on the main altimeter to marginal on the 2" altimeter. The subjects' ratings of the instrument's usability was satisfactory. On ground attack, PAR, barrel roll, and climbout, one subject rated the altimeter usability as unsatisfactory. He commented that the last three painted zeros on the face of the instrument and the two-hundred foot altitude transition level for the next higher thousand foot number coming into view on the drum could cause a pilot to make one thousand foot errors in reading his altitude. Four other subjects made the same comment. Only one subject was actually observed to make this error during the data collection flights.

Directional Gyro Indicator:

Only seven subjects evaluated the 2" directional gyro indicator due to indicator failure prior to completion of the test program. In all high-dynamic flight, the indicator precessed considerably and had to be reset after high energy maneuvering was completed. During these maneuvers, the subjects who evaluated the indicator were requested to evaluate its usability, assuming it was working properly. On all the maneuvers except steep turns and penetrations, the subject pilots' performance was as accurate on the 2" directional gyro indicator as it was on the main heading indicator. During steep turns, two subjects' performance dropped from an excellent on the main system to a satisfactory on the 2" system. During one penetration, one subject's performance dropped from an excellent on the main system to satisfactory on the 2" system. The subjects' ratings of the 2" directional gyro indicator's usability ranged from excellent to unsatisfactory. Fifty percent (50%) of the total usability ratings on all maneuvers were satisfactory, thirty percent (30%) were marginal, thirteen (13%) were unsatisfactory, and seven (7%) were excellent. Four of seven subjects commented that small heading inputs were difficult to make due to the size of the instrument. It was also noted that cardinal headings need to be cosmetically emphasized for easy reference. It was impossible to tell which mode, DG or mag, was selected without physically rotating the control to see what position was selected. All subjects stated the accuracy of the 2" directional gyro indicator was unacceptable in high dynamic flight due to precession.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions:

- a. Pilot performance on the 2" Standby Instrument System was adequate to satisfactorily perform all the maneuvers evaluated.
- b. Subject pilots were required to focus more attention and concentration on the 2" system to achieve the same level of performance that they did on the aircraft's main instruments.
- c. The 2" attitude indicator, airspeed/mach indicator, and altimeter should be installed in Air Force aircraft only after the cosmetic changes that are stated in the recommendations have been accomplished.
- d. The 2" directional gyro indicator, as tested, should not be installed in Air Force aircraft because of excessive precession in high dynamic flight. Additionally, the instrument did not prove to be functionally reliable enough in either the pre-validation or data collection phases to recommend acceptance in its current design stage.
- e. The location of any standby instrument package is just as important in the pilot/aircraft interface as the design of the primary instrument system.

Recommendations:

1. General:

a. As much consideration must be given to cockpit design and to the positioning of any standby instrument system as is given to the positioning of the primary system. For optimum effectiveness, the standby instruments should be arranged to provide the same cross-check pattern to the pilot as does his primary system. Additionally, the standby instrument should be cosmetically identical and have calibrated increments the same as the main system.

b. Wherever possible, aircraft should be equipped with effective covers or masking devices for the primary instruments to be used in the event of instrument failure. A failed primary instrument that remains in a pilot's field of view will constantly be included in his cross-check. The constant reassessment and reevaluation of the failed instrument(s) in the pilot's cross-check can cause a conflict to develop that could effectively make accomplishment of a given instrument maneuver unsatisfactory.

c. Standby instrument training should be made an integral part of a pilot's upgrade training, continuation training, and flight evaluation to insure a pilot's capability to competently use the system when the need arises.

2. Specific:

a. Attitude Indicator: A bank pointer should be placed at the top of the indicator. The off flag should be a function of gyro speed instead of power interruption failure which would then indicate to the pilot the relative usability of the indicator as the gyro spins down. This might be done by designing an off flag which starts coming into view when the gyro begins to lose speed and continues coming into view at a rate proportional to the effective useful range of the gyro as it spins down. The first part of the flag should be yellow in color changing to red as more of the flag comes into view. This off flag would indicate to the pilot that the gyro is still usable as the gyro spins down until the off flag turns red. Then the gyro is unusable.

b. Airspeed Indicator: Place the number "3" in line with the 300 knot tick mark. Place a decimal point in front of the mach number instead of the small circle. Incorporate a moveable airspeed reference marker into the indicator to allow a predetermined airspeed to be more precisely maintained.

c. Altimeter: The three painted zeros on the face of the instrument should be removed. Reduce span of change over which the drum changes to the next higher or lower thousand foot indication from

two hundred feet to less than one hundred feet to reduce the possibilities of misinterpretation.

d. Directional Gyro Indicator: Cardinal headings need to be emphasized for easy reference. Put some indication on the control knob to indicate which mode (DG or MAG) is selected.

Primary/Standby Instrument Ratings

Performance

ITO

Attitude Indicator
Airspeed Indicator
Altimeter
Heading Indicator

U	M	S	E

STEEP TURNS

Attitude Indicator
Airspeed Indicator
Altimeter
Heading Indicator

U	M	S	E

UNUSUAL ATTITUDES

Attitude Indicator
Airspeed Indicator
Altimeter
Heading Indicator

U	M	S	E

BARREL ROLL

Attitude Indicator
Airspeed Indicator
Altimeter
Heading Indicator

U	M	S	E

REMARKS:

Name _____ Flight _____

Primary/Standby Instrument Ratings

Performance

LOOP

Attitude Indicator
Airspeed Indicator
Altimeter
Heading Indicator

U	M	S	E

GROUND ATTACK

Attitude Indicator
Airspeed Indicator
Altimeter
Heading Indicator

U	M	S	E

PENETRATION

Attitude Indicator
Airspeed Indicator
Altimeter
Heading Indicator

U	M	S	E

PAR

Attitude Indicator
Airspeed Indicator
Altimeter
Heading Indicator

U	M	S	E

REMARKS:

Name _____ Flight _____

Primary/Standby Instrument Ratings

Usability

ITO

Attitude Indicator
Airspeed Indicator
Altimeter
Heading Indicator

U M S E

STEEP TURNS

Attitude Indicator
Airspeed Indicator
Altimeter
Heading Indicator

U M S E

UNUSUAL ATTITUDES

Attitude Indicator
Airspeed Indicator
Altimeter
Heading Indicator

U M S E

BARREL ROLL

Attitude Indicator
Airspeed Indicator
Altimeter
Heading Indicator

U M S E

REMARKS:

Name _____ Flight _____

Primary/Standby Instrument Ratings

Usability

U M S E

LOOP

Attitude Indicator
Airspeed Indicator
Altimeter
Heading

U M S E

GROUND ATTACK

Attitude Indicator
Airspeed Indicator
Altimeter
Heading Indicator

U M S E

PENETRATION

Attitude Indicator
Airspeed Indicator
Altimeter
Heading Indicator

U M S E

PAR

Attitude Indicator
Airspeed Indicator
Altimeter
Heading Indicator

REMARKS:

Name _____

Flight _____

POST FLIGHT INTERVIEW

1. In your opinion, how would you rate your overall performance on this flight?
(Check one box)

- Excellent
- Satisfactory
- Marginal
- Unsatisfactory

2. Rate your performance on the following maneuvers:
(Use E, S, M, or U)

- a. ITO _____
- b. Steep Turns _____
- c. Unusual Attitudes _____
- d. Loop _____
- e. Barrel Roll _____
- f. Air-to-Ground _____

3. What span of time, if any, has elapsed since your last opportunity to fly and/or practice the following maneuvers?

- a. ITO _____ days _____ weeks _____ months
- b. ST _____ days _____ weeks _____ months
- c. UA _____ days _____ weeks _____ months
- d. Vert S _____ days _____ weeks _____ months
- e. Loop _____ days _____ weeks _____ months
- f. Barrel Roll _____ days _____ weeks _____ months

4. List the three most important instruments in their order of importance used by you when performing the following maneuvers:

- a. Steep Turns _____ 1 _____ 2 _____ 3
- b. Unusual Attitudes _____ 1 _____ 2 _____ 3
- c. Loop _____ 1 _____ 2 _____ 3
- d. Barrel Roll _____ 1 _____ 2 _____ 3
- e. Air-to-Ground _____ 1 _____ 2 _____ 3
- f. Instrument Approaches _____ 1 _____ 2 _____ 3