ESL-TR-81-05

AD A127712

PHOTOGRAPHIC SMOKE ANALYSIS OF THE T-56 ENGINE

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JUNE 1981

FINAL REPORT
6 FEB 1980 - 15 MAY 1981

AFESC

ENGINEERING & SERVICES LABORATORY
AIR FORCE ENGINEERING & SERVICES CENTER
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83 05 06 - 057

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: ESL-TR-81-05
2. GOVT ACCESSION NO.: AD-A127 712
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): PHOTOGRAPHIC SMOKE ANALYSIS OF THE T56 ENGINE
5. TYPE OF REPORT & PERIOD COVERED: FINAL REPORT, 6 FEB 1980 - 15 MAY 1981
6. PERFORMING ORG. REPORT NUMBER: TR - 8003
7. AUTHOR(s):
Lawrence A. Mattison
Robert E. Kinzly
Donald J. Nixon
8. CONTRACT OR GRANT NUMBER(s): F33700-80-C-0009, PO NUMBER 142725SPD
9. PERFORMING ORGANIZATION NAME AND ADDRESS:
SCIPAR, Inc.
P.O. Box 185
Buffalo, NY 14221
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: JON: 1900 2027, PE62601F
11. CONTROLLING OFFICE NAME AND ADDRESS:
Air Force Engineering and Services Center
Tyndall AFB, Florida 32403
12. REPORT DATE: JUNE 1981
13. NUMBER OF PAGES: 132
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
15. SECURITY CLASS. (of this report): UNCLASSIFIED
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:
16. DISTRIBUTION STATEMENT (of this Report):
Distribution Unlimited: Approved for public release.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):
18. SUPPLEMENTARY NOTES:
Availability of this report is specified on reverse of Front Cover.
19. KEY WORDS (Continue on reverse side if necessary and identify by block number):

VISUAL DETECTION	PHOTOMETRY
SMOKE	PHOTOGRAPHY
VISIBILITY	EXHAUST
FLIGHT TEST	T56 ENGINE
OPACITY	SMOKE NUMBER

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the results of flight tests performed to evaluate exhaust plume visibility of a C-130-H Aircraft powered by four Allison T56-A-15 engines. Measurements of the smoke densities were made using calibrated photographic methods and visual emission readings. The photographic images were photometrically analyzed to produce plume transmission maps that were compared to engine Smoke Numbers and visual opacity readings. A visible/invisible threshold ranging between Engine Smoke Numbers from 33 to 48 was found.

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PREFACE

This final report documents work accomplished by SCIPAR, Inc., P.O. Box 185, Buffalo NY 14221, under Contract F33700-80-G-0009 for the Air Force Engineering and Services Laboratory, Tyndall AFB FL. The report covers tests during the period, 1 January 1980 through 1 June 1980, and subsequent data analyses during the period, 1 June 1980 through 15 May 1981. This work was accomplished under Program Element 62601F, Project 19002027. The project officer in charge of coordinating the test program and analyses was Maj John T. Slankas.

This report reviews the state of the art in defining test procedures and analyses for photographic/photometric measurement of the exhaust plume visibility. The overall program objective was to obtain data from flight and ground tests to determine the apparent optical transmission and degree of visibility of the smoke exhaust and then relate the data to the engine Smoke Number (SN).

This report summarizes work done between 1 June 1980 and 15 May 1981. The AFESC Project Officer was Major John T. Slankas.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

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SECTION 1

1.0 INTRODUCTION

A study of the exhaust plume visibility of a C130-H Aircraft powered by four Allison T56-A-15 engines was coordinated by the Air Force Engineering and Services Center (AFESC). This report documents SCIPAR's work effort in defining test procedures and analyses for photographic/photometric measurement of the exhaust plume visibility. The overall program objective was to obtain data from flight and ground tests to determine the apparent optical transmission and degree of visibility of the smoke exhaust and relate the data to the engine Smoke Number (SN).

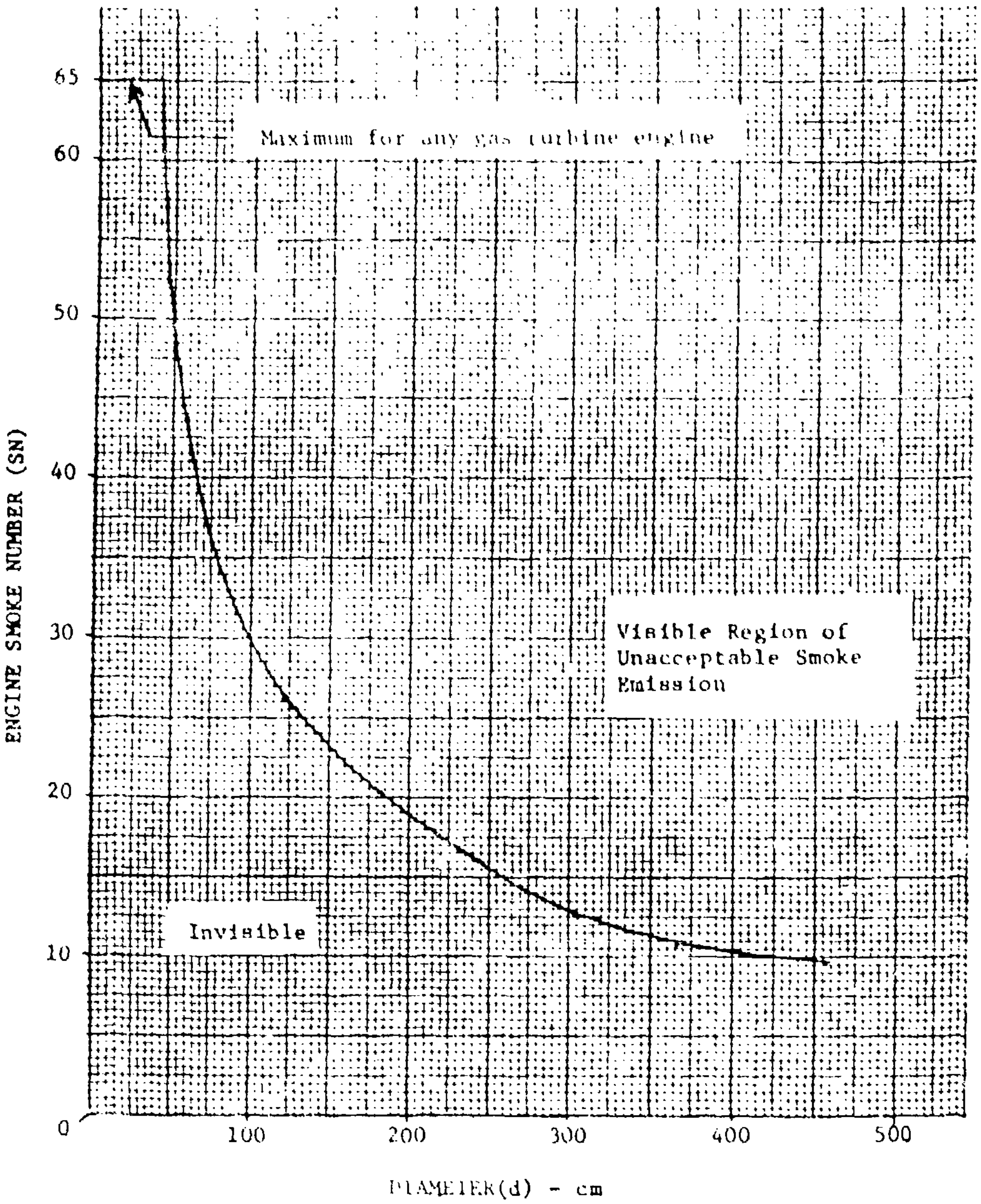
The Air Force and The Environmental Protection Agency (EPA) have each published smoke limit specifications based upon measured thresholds of exhaust plume visibility; however, they differ significantly. Figure 1 illustrates the Air Force specifications for visisble and invisible smoke as they relate to the Smoke Number of an engine measured by the method of SAE ARP 1179 and using MIL-T-5624 grade JP-5 fuel. The exhaust diameter of the T56 engine is approximately 50 cm; therefore, as seen from the graph, the Air Force Smoke Number requirement to insure that the smoke is not visible is about 50. For comparison, the 1973 EPA emission standards for the class "P2" (all turboprop) engine with an operating shaft horsepower between 4,000 and 5,000 is shown in Figure 2. The plot in the lower right corner of this figure suggests that the appropriate Smoke Number is about 29. Proposed revisions to the 1973 EPA Standards were issued in 1978. Under the new specifications, the maximum Smoke Number allowable is identified as:

$$SN < 277 \times (r_o)^{-0.280}$$

r_o = rated output power available for takeoff with standard day conditions in kilowatts

For the T56 engine, r_o is approximately 3355 kilowatts. Therefore the maximum smoke number specification is:

$$SN < 277\ (3355)^{-0.280} \cong 29$$



d: Diameter of the vitiated airflow exhaust nozzle at the engine exhaust exit plane. The exhaust exit plane is the first downstream plane, normal to the exhaust stream, that does not contain a solid surface around the stream. For engines with vitiated airflow leaving the engine through an annulus, (d) shall be the diameter of a circle having the same cross-sectional area as the annular exhaust stream.

Figure 1. Air Force Visible/Invisible Specification

The new specification provides the mathematical equivalent of the 1973 requirement graph shown in Figure 2.

The discrepancy between the Air Force limit of 50 and the EPA limit of 29 was a primary motivation for conducting this program. Each method, however, is not based on quantitative measurements of the light transmission of the smoke plume. Use of the calibrated photometric techniques discussed in this report provides a more precise determination of the observable smoke level for input to turboprop engine smoke standards.

Since the concern of this program was to relate the measured Smoke Number of the T56 engine to the plume transmission, it must be recognized that the Smoke Number and permissible smoke levels actually correlate differently, dependent upon each particular application. A test conducted by the Air Force Aero Propulsion Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base (APTR-TM-69-11) provides an example by examining smoke visibility in a situation involving a four-engine jet airliner during takeoff. All engines were identical in size and performance and all produced the same measured smoke level. Together, however, the four generated a heavy blanket of exhaust smoke that was extremely visible, whereas the smoke from a single engine of the same type was not as apparent. The reason for this result is that the smoke from the single engine can disperse more quickly. The Photographic data collected for the present program, therefore, represents the four T56 turboprops on the C-130 as an interactive group rather than single engine smoke visibility that would relate to the single engine Smoke Number.

The visible/invisible threshold (98 percent average plume Transmission) for the multiple-engine C-130 was determined to be within a Smoke Number range of 33 to 48. As discussed in Section 4.2, Photographic Versus Smoke Number, a large amount of variability of the apparent plume transmission from run to run was found and did not allow the specification of a single threshold. Among the major contributors to the smoke transmission variability were the multiple-engine smoke interaction, variable plume viewing aspects, sky background brightness levels, and localized atmospheric conditions. Comparison of the photographic data to visual observer opacity readings is discussed in Section 4.1, Photographic Versus Visual however, no correlation between the methods could be found because of inconsistencies within the observer visual readings.

EPA ENGINE EMISSION STANDARDS

17 JULY 1973

Engine Class	Air Pollutants	New and in-use engines Jan 1, 1974	Jan 1, 1976	Jan 1 1978	Engines manufactured on or after Jan 1, 1979	Dec 31, 1979	Jan. 1, 1981 (Newly Certified)
T1	HC lbs/1000 lb-thrust-hrs/cycle				1.6		
	CO "				9.4		
	NO_x "				3.7		
	SMOKE				Figure 1		
T2	HC "				0.8		0.4
	CO "				4.3		3
	NO_x "				3		3
	SMOKE		Figure 1 R		Figure 1		Figure 1
T3	HC "				0.8		0.4
	CO "				4.3		3
	NO_x "				3		3
	SMOKE			SN of 25	Figure 1		Figure 1
T4	HC "				0.8		0.4
	CO "				4.3		3
	NO_x "				3		3
	SMOKE	SN of 30			Figure 1		Figure 1
P1	HC lb./rated power/cycle					.0019	
	CO "					.042	
	NO_x "					.0015	
P2	HC lbs./hp-hrs/cycle				4.9		
	CO "				26.8		
	NO_x "				12.9		
	SMOKE				Figure 2		
APU	HC lb./1000 hp-hr of power output				0.4		
	CO "				5		
	NO_x "				3		

No fuel venting emissions shall be discharged from T2, T3, T4, or T5 engines after January 1, 1974. T1 or P2 after January 1, 1975

No emission requirements for T5 except fuel venting emissions.

Definitions:

T1-Turbofan or turbojet engines, except T5 engines, with less than 8,000 pounds thrust.

T2-Turbofan or turbojet engines, except T3, T4 and T5, with 8,000 pounds thrust or greater.

T3-Gas turbine engines of the JT3D model family.

T4-Gas turbine engines of the JT8D model family.

T5-Gas turbine engines employed for propulsion of aircraft designed for supersonic speeds.

P1-Aircraft piston engines except radial engines.

P2-Aircraft turboprop engines

Newly certified engines-Gas turbine engine which is type certified on or after the effective date of the applicable emission standard

APU-Any engine installed in or on an aircraft exclusive of the propulsion engines.

Fuel venting emissions-All raw fuel exclusive of hydrocarbons in the exhaust emissions discharged from gas turbine engines

Rated power-Maximum power/thrust available for take off at standard day conditions.

R T2 with 29,000 pounds thrust or greater

FIGURE 1

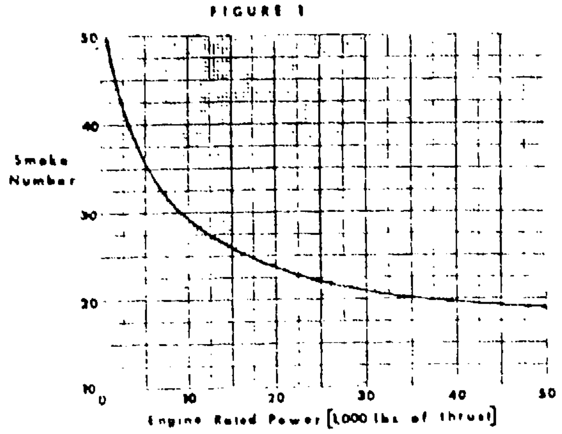
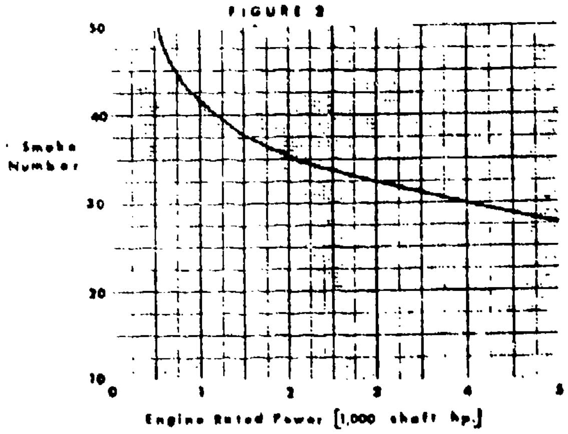


FIGURE 2



Prepared by Naval Air Propulsion Test Center

Figure 2. EPA Engine Emission Standards

SECTION II

2.0 TEST PROGRAM

The test program included a coordination meeting on 18 March 1980 and flight/ground testing on 20 May 1980 at Edwards Air Force Base. Organizations involved in the Work effort included HQ AFESC/RDV; Air Force Logistics Center, 6510th Test Wing, Logistics Squadron (Special) Detachment 4; Operations Test Center (OTC, EAFB); Detroit-Diesel Allison (DDA General Motors); and SCIPAR, Inc. Each group provided support in the development of the test plan and in the performance of the tests and data collection. This section describes the procedures, conditions, and collection methods used in carrying out the program and obtaining the required data.

2.1 Instrumentation

The equipment and supplies used in the collection of the exhaust plume data are discussed below.

2.1.1 Cameras

For collection of photographic data during the tests, two 35 mm format cameras were utilized. SCIPAR and OTC each provided a Canon F-1 camera for the task. Each camera was equipped with a 250-exposure film back, motor drive, automatic exposure control, and a 100 mm lens with a Wratten No. 8 yellow filter. The photographic film/filter system was designed to obtain a spectral response approximating the eye (photopic).

Each component of the camera system had been selected to provide maximum flexibility. The 250-exposure film chamber was utilized so that time between 36-exposure standard film changes was not lost. Use of standard film lengths would require access to the camera on the tracking platform, rewinding the film, and reloading the camera. With the 250-exposure film chamber the reloading was infrequent and film rewinding was not necessary. The motor drive unit on each camera was required for automatic advancement of the film while it was on the tracking platform. Manual film advance after each photograph would not have been practical. The automatic exposure control was also necessary because of restricted access to the tracking platform access. This unit provided the correct exposure for each photograph,although the sky brightness varied throughout the test. The correct film exposure is required for an accurate analysis of the photographic imagery. To obtain records of the sky background brightness at the time of the test a SpectraSpot ½° Field-of-View photometer was used.

2.1.2 Photographic Film

The selection of the photographic film for the data collection is dependent upon the information required; in this case, the ratio of the amount of light from the smoke plume to the amount of light from the background (transmission of the plume). In anticipation of high plume transmissions (95-98 percent), the brightness of the plume was expected to be very close to the brightness of the background. For data analysis purposes, it was advantageous to exaggerate this difference during film recording so that the differences could be easily measured. When the film measurements are completed, a computer analysis program converts the photographic information back to the relative brightness of the scene.

Specification of film was based on the minimum plume transmission to be measured and the minimum density change on the film that can be measured. The Perkin-Elmer Micro 10 microdensitometer at SCIPAR is able to measure density differences accurately to less than 0.02. The plume transmissions to be measured during flight tests were expected to be as high as 98 percent. When the smoke plume is photographed, the transmission of the plume is:

$$\text{Transmission of plume} = T = \frac{B_s}{B_o} = 10^{-\Delta D/\gamma}$$

where

B_s is the apparent brightness of the smoke

B_o is the apparent brightness of the background

ΔD is the measured density difference on the film

γ (gamma) is the contrast (or gain) of the film measured using sensitometric calibration.

From this relationship the minimum required film contrast can be found. Using the maximum smoke transmission of 98 percent:

$$.98 = 10^{-\Delta D/\gamma}$$

so

$$\frac{\Delta D}{\gamma} = 0.009$$

and

$$\Delta D = 0.009$$

Input of the minimum measureable $\Delta D = 0.02$:

$$\gamma = 2.22$$

Therefore, the minimum film contrast (or gamma) required for the test is 2.22. It should be kept in mind, however, that this assumes minimum measurable change in density on the film. For purpose of accuracy, a greater change in density and, hence, a higher film contrast is desirable. Table 1 illustrates the change in density that would be measured on films of various degrees of contrast for smoke transmissions of 95 and 98 percent. Using contrast film of γ = 3 to 4 provides an accurate recording and analysis method for plume transmission up to 98 percent.

TABLE 1. CHANGE IN FILM DENSITY VERSUS PLUME TRANSMISSION

Transmission of Plume	ΔD		
	$\gamma = 2.2$	$\gamma = 3.0$	$\gamma = 4.0$
98%	0.02	0.03	0.04
95%	0.05	0.07	0.09

Based on data obtained from Eastman Kodak Company for Technical Pan Film (EK 2415) indicating contrasts of $\gamma = 3$ to $\gamma = 4$, preliminary sensitometric tests of the film were conducted at OTC's Photographic Laboratory. A film contrast of $\gamma = 3.99$ was found from these tests using standard procedures in a Versamat® processor at 5 feet per minute with Hunts 500 developer at 79.8°F. Since this film contrast was desirable based on the defined requirements, it was used in the flight/ground tests. The data release document P-255 from Kodak which provides a complete description of the film is supplied in Appendix A. Four 100 ft rolls of the Kodak Technical Pan Film were supplied by OTC.

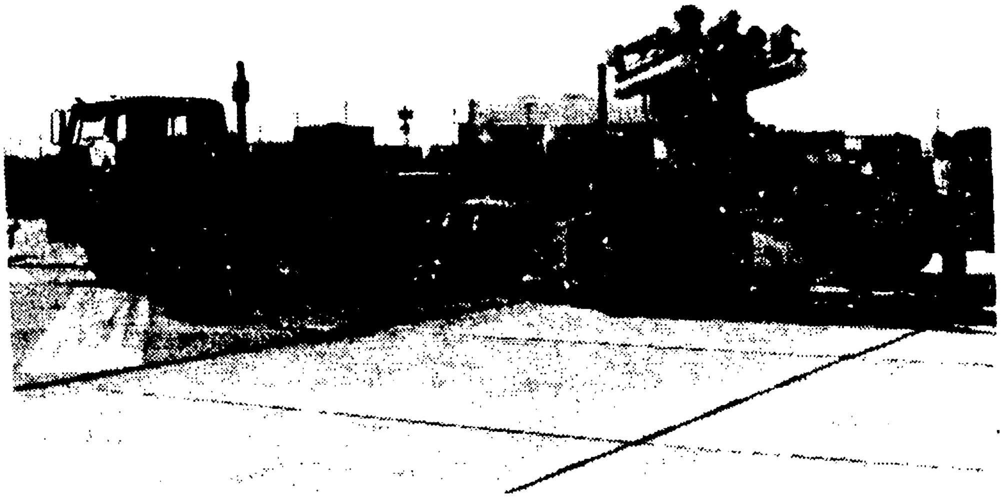
As previously noted, the proper exposure level during the flight test was required to provide good images for analysis. The primary concern is the resultant density of the sky background on the film. The dark smoke will always appear less dense on the negative image and, therefore, a sufficient background density is required on the negative. Also, by assuring that the exposure is at a level where the film is most sensitive to varying image brightnesses the analysis software can more precisely calculate the plume transmission. Based on a test series of photographs taken, the ASA film speed on the automatic exposure controller was set at 80 to produce an expected sky background density on the film of 2.3 (based upon the processing conditions used in the preliminary test).

2.1.3 Smoke Meter

Measurement of the exhaust smoke from one engine during ground tests, as defined in the Society of Engineers Aeronautical Recommended Practice, ARP 1179, required equipment that was supplied by DDA/GM. A smoke meter, smoke probe, and sample line for measurement of the engine/fuel Smoke Number were provided.

2.1.4 Tracking Platforms

Two manual tracking platforms were supplied by OTC for use in the flight tests. One tracker was a large manually-controlled, motor-driven platform. This tracker contained Camera #1 and other cameras used for documentation purposes. The tracking operator controlled the platform using hand controls. Photographs illustrating the tracker and equipment are provided in Figure 3. The second tracker was a small tripod-type platform for backup which was used to hold one 35 mm camera (Camera #2). The tracking operator stood on the ground and sighted through the camera viewfinder to track the aircraft.



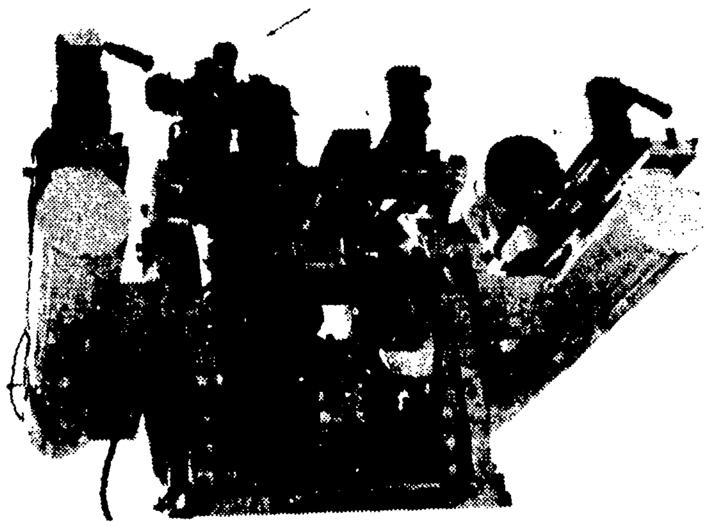


Figure 3. Tracking Platform and Camera #1

2.2 Ground Tests

To relate the smoke plume optical transmission to the measured Smoke Number of the T-56 engine at various power settings, ground runup tests were made. The smoke from engine Number 2 (A/C C-130H, No. 73-1586, Eng. T56-A-15, Serial No. AE106872) was measured at flight idle, approach, cruise, and climb power settings for JP-4 and JP-5 fuels. Smoke data was collected using a smoke meter, photography, and two certified visual emission readers from USAF Occupational and Environmental Health Laboratory (USAF OEHL). Figure 4 illustrates collection of Smoke Number data from the engine using the DDA/GM smoke meter.

Data collected during the ground runup tests in addition to calibrated photography taken perpendicular to the plume include engine rpm, fuel flow, torque, turbine inlet temperature, and oil consumption. A record of the ambient environmental conditions was also required since these conditions could effect the quantities of smoke produced.

The ground tests were conducted on 20 May 1980 from 1352 hours to 1439 hours during ambient air temperatures of 91.4°F to 95.8°F. The measured atmospheric pressure was 27.42 inches of Hg and relative humidity was 16%.

2.3 Flight Tests

The flight tests were held at the North Base Runway 06-24 at Edwards AFB. Based on photographic measurement requirements and EPA requirements for observation of visual opacity of smoke emissions, the data was collected with the sun at the back of the observers. The flight sorties included normal takeoffs, fly-bys, and approach and landings using JP-4 and JP-5 fuels.

Takeoffs and landings were accomplished to and from the west and a race-track flight pattern was selected. Figure 5 illustrates a scaled approximation of the flight path and locations of the observers and tracking platforms. The solid portion of the flight paths indicate the location of the aircraft when smoke transmission data was recorded. Point A was an average of 17 Kft from Point B and represents the beginning of the inbound portion of the flight path. At airspeeds of 200 to 300 knots (340 to 500 fps) each inbound sequence provided approximately 40 seconds for data collection.

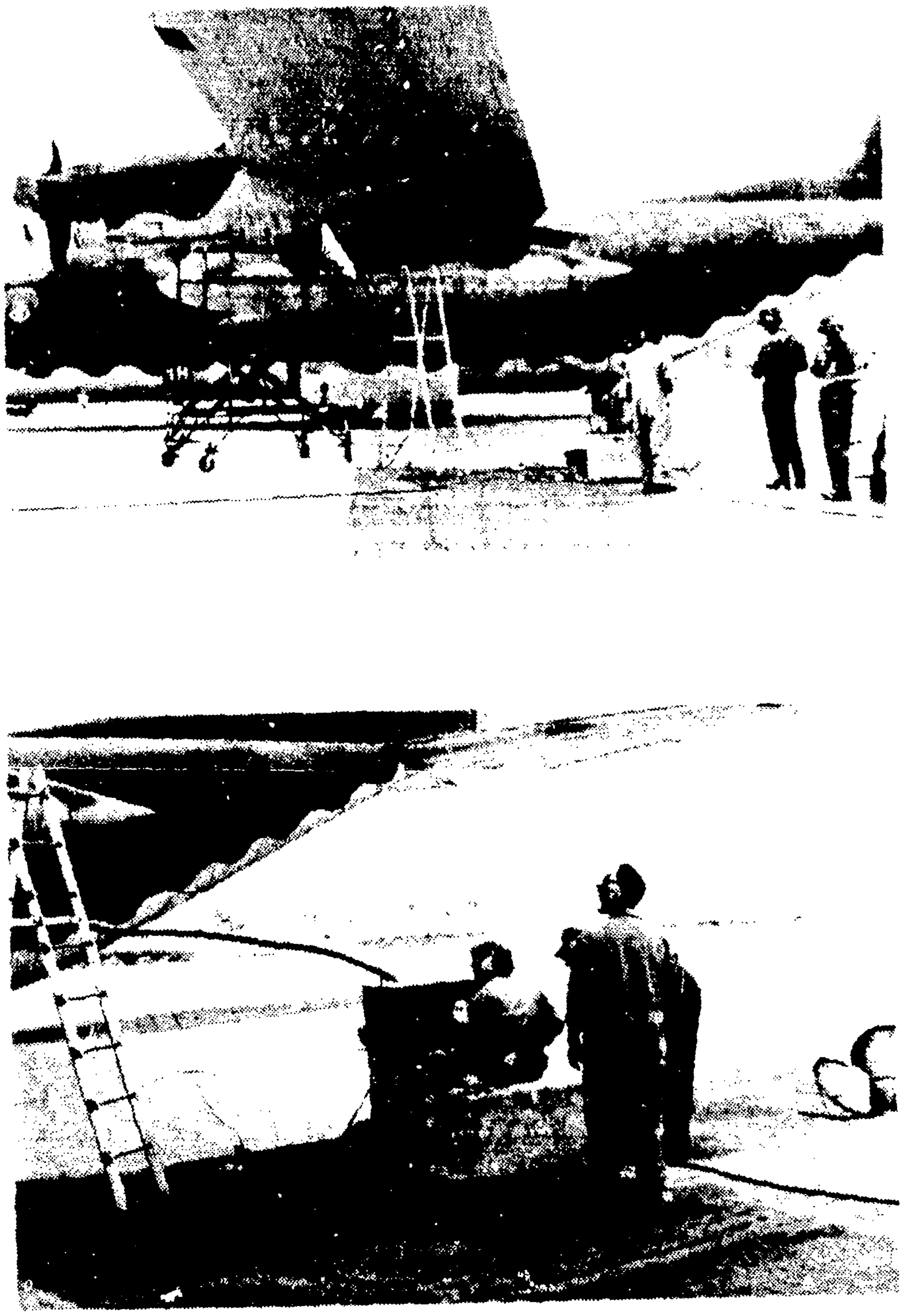


Figure 4. Smoke Number Data Collection - Ground Runup

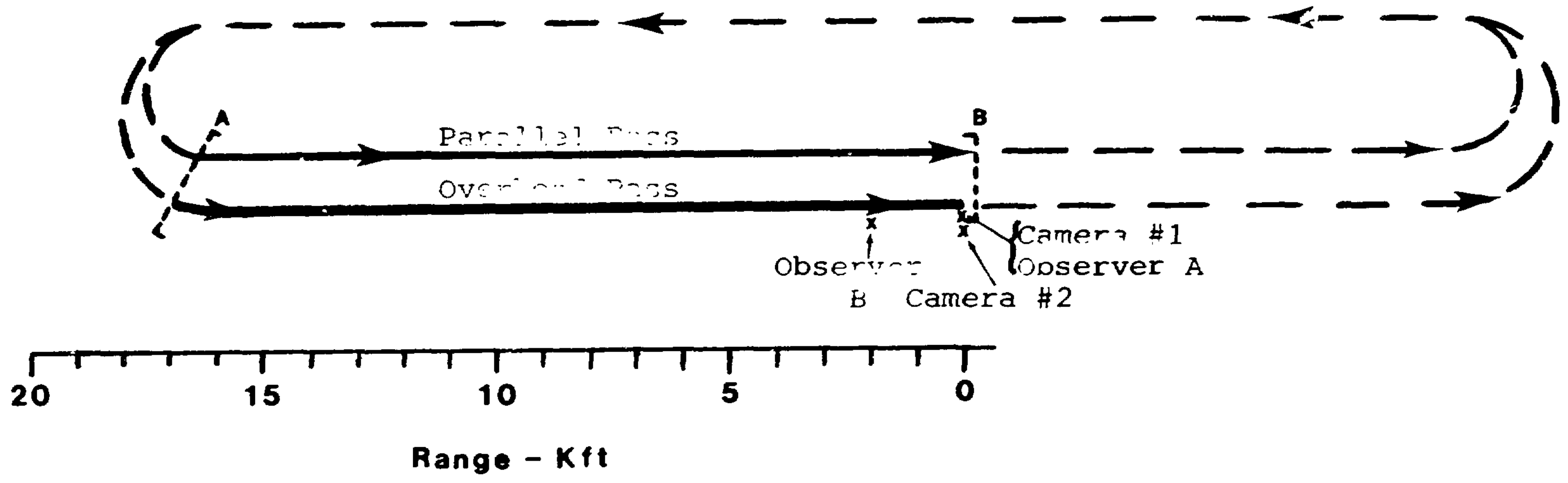


Figure 5. C-130 Racetrack Flight Pattern

The observers and recording cameras were located on the south side of the runway. Camera #1 mounted on the larger tracker was located on the edge of the runway along with a visual opacity observer (TSgt. John Vlasko, Air Quality Technician). Camera #2 (for backup) was positioned 300 ft. offset from the runway as illustrated in Figure 5. The second visual opacity observer (Capt. John E. Stevens, Jr., Air Resources Engineer) was located on the edge of the runway approximately 2000 ft. West of the cameras. The separate positions were selected to provide slightly different viewing aspects for each observation made. As illustrated by the geometry of the scaled drawing showing the flight path, however, the fly-in from 17 Kft range provided similar viewing aspects for each of the three positions for most of the inbound sequence. For the average flight altitude of 400 ft. and track ranges of 17 Kft to 5 Kft, the observer viewing elevation angles for Sgt. Vlasko and the two cameras were 1.4° to 4.6° and those for Capt. Stevens were 1.5° to 7.6°.

Data recorded on the aircraft during the flight test includes each engine horsepower, fuel flow, torque, turbine inlet temperature, altitude, airspeed, and aircraft configuration. Ambient conditions at the time of the flight tests (20 May 1980, 0830 hours to 1021 hours) included measured air temperatures of 67°F to 78°F, and atmospheric pressure of 27.51 inches of Hg. The wind speed ranged from 2 mph to 0 mph at a 10° heading. The visibility varied from 45 miles to 35 miles.

During the flight test period scattered and broken clouds caused problems in making smoke transmission measurements. The clouds were documented at 20 Kft altitude with coverage increasing from 10 to 70 percent during the tests. When the smoke plume is viewed against a nonuniform brightness sky or cloud background, the visual and photographic methods of measuring the plume transmission are hindered.

The camera shutter controls on the two cameras were electrically connected to provide synchronized photographs of the smoke plume. The photographic sequence was started at the beginning of each inbound portion of the C-130 flight at a rate of one frame every five seconds. The first observer, Sgt. Vlasko, recorded visual opacity data with each photograph. The second observer, Capt. Stevens, recorded visual opacity every 15 seconds throughout the test.

A problem with Camera #1 was not discovered until the end of the flight sequences. The camera was mounted on the tracker without covering of the viewfinder on the rear of the camera after the system was boresighted. With sunlight entering the viewfinder, the automatic exposure sensor determined improper camera exposure settings, causing the recording film to be extremely underexposed and eliminating its use for data analysis. The backup camera at 300 ft. offset, however, provided data at similar viewing aspects for a large percentage of the inbound sequence as previously described. For the ranges of 17 Kft the viewing azimuth difference ranged from 1° to 3.5°.

SECTION III

3.0 DATA ANALYSIS

The basic photometric analysis scheme is illustrated in Figure 6. The film record of the smoke plume during the tests was developed using calibrated photographic processing in an OTC automatic processor. Image analysis was then conducted at SCIPAR by scanning the film with a microdensitometer to convert the image to digital input for the computer. The computer analysis of the digitized image produced a map of the smoke plume that showed the ratio of the plume brightness to the brightness of the adjacent sky background (apparent transmission).

3.1 Photographic Processing/Development

When the black-and-white films of the flight test were processed, a method of calibration (sensitometry) was required. A 21-step exposure tablet in a sensitometer was used to expos blank portions of the flight test film so that the step images could be processed with the flight test images. The exposure and processing of the step tablet provided information necessary for relating the densities measured from the film to the amount of light that exposed the film (sky background brightness can be compared to smoke plume brightness).

Processing of the test film was conducted at the EAFB OTC Photographic Labortory. OTC provided a Kodak 101 Sensitometer to expose several step tablets on various portions of the test film for use in measurement of the film sensitometric characteristics. The absolute exposures produced on the film at each step are provided in Table 2. Five step tablets were used during processing for evaluation of the film response throughout the development sequence, i.e. film speed, contrast. The resultant film densities produced from each step exposure are discussed and plotted in Section 3.2.1, Methodology.

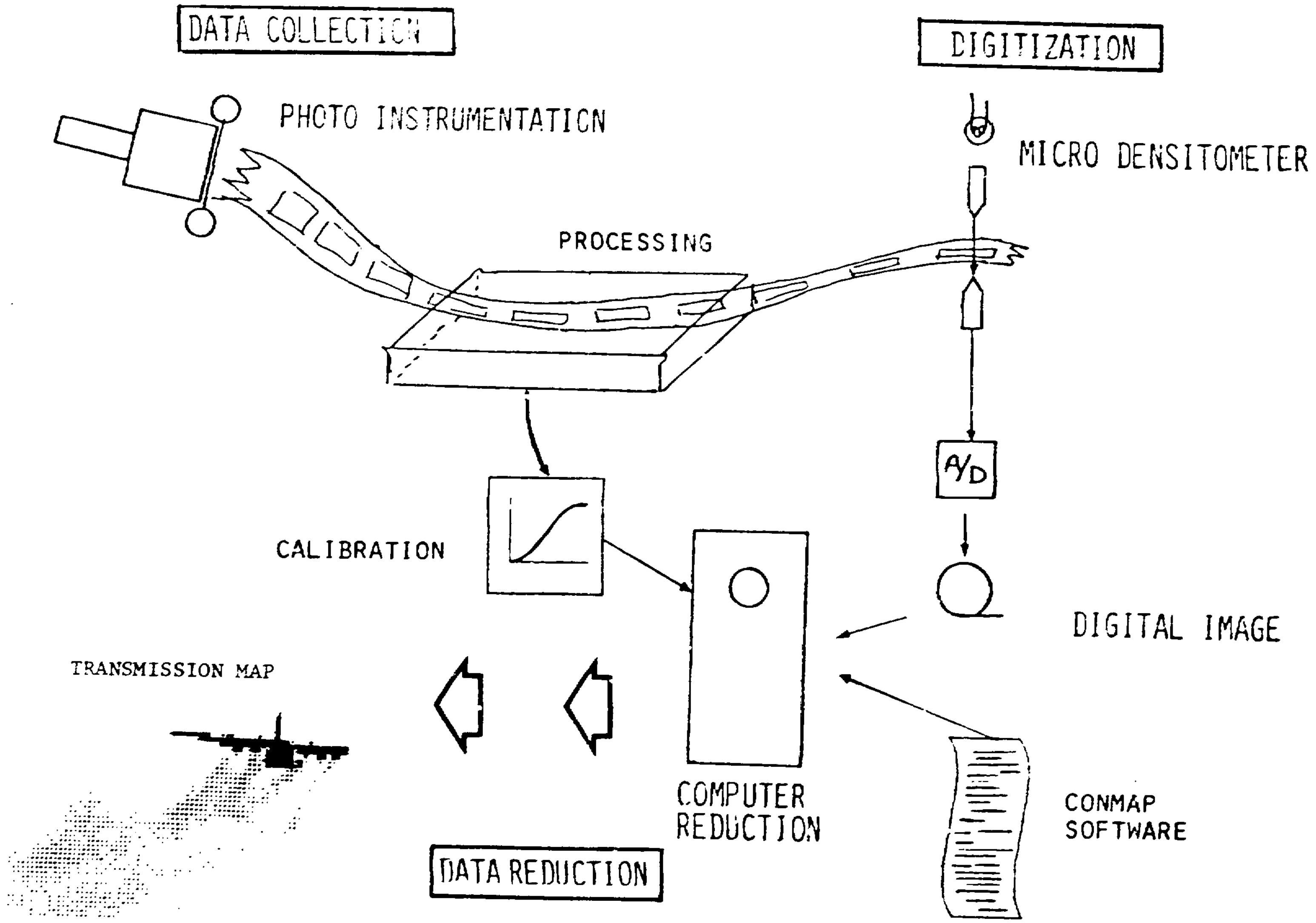


Figure 6. Photographic Data Collection/Reduction Flow Diagram

TABLE 2. ABSOLUTE EXPOSURE AT EACH STEP

STEP	EXPOSURE ($\frac{LUX}{SECS}$)	LOG_{10} EXPOSURE
1	0.0025	-2.82
2	0.0020	-2.70
3	0.0031	-2.51
4	0.0044	-2.36
5	0.0063	-2.20
6	0.0085	-2.07
7	0.0126	-1.90
8	0.0182	-1.74
9	0.0257	-1.59
10	0.0363	-1.44
11	0.0537	-1.27
12	0.0759	-1.12
13	0.1072	-0.97
14	0.1514	-0.82
15	0.2138	-0.67
16	0.3020	-0.52
17	0.4266	-0.37
18	0.6026	-0.22
19	0.8511	-0.07
20	1.2023	0.08
21	1.6982	0.23

The film was processed in a Versamat® processor at 5 feet per minute with Hunts 500 developer at a temperature of 80.8°F. No major problems were encountered in utilizing the OTC facility and the maximum length of film that could be processed was unlimited. The processing sequence was completed in less than 2 hours. The imagery processed included approximately 500 frames from the two cameras used in the flight test and 100 frames from the ground test film.

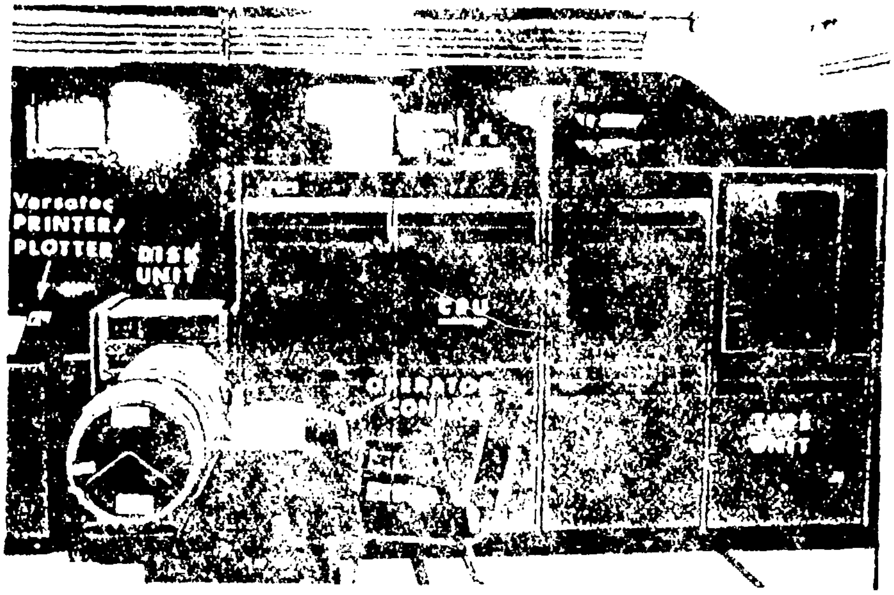
3.2 Analysis Procedure

A Perkin-Elmer Micro 10 microdensitometer and Digital VAX 11/780 Computer System at SCIPAR were used (illustrated in Figure 7) for analysis of the test films. The microdensitometer digitized the photographic images, recording the densities over a matrix of the image on digital tape. The aperture size selected for scanning the image, dependent on the overall image size, was 0.050 mm (50 μm). The recorded data tape was then transferred to the VAX computer for exposure/contrast analysis and production of plume apparent transmission maps using SCIPAR CONMAP software.

3.2.1 Methodology

The image location on the film was identified for input to the microdensitometer since a restricted portion of the film was scanned. Coordinates identifying the location of the smoke plume image and areas of the background sky image on each photographic frame were obtained using a grid overlay with 1 mm spacing. Using visual examination, the plume image location was identified using the bottom right corner of each frame as a reference point. The area scanned on each frame containing the smoke plume had dimensions of 5 mm by 6 mm. Within this area the density of the image was measured at 12,000 positions on a matrix with a 50 μm spacing. The scanning sequence utilized for each image provided a specific order in which the data was recorded that allows the computer to reconstruct a map or "picture" of each image. The scanning sequence for the film examined used 120 scan lines, each containing 100 density readings. The relative position of each of the readings (pixels) on the images are illustrated in Figure 8.

Measurements of the background density level were made by scanning three 5 mm by 1 mm areas of the image adjacent to the smoke plume on each frame.



DIGITAL VAX 11/780 COMPUTER SYSTEM

PERKIN ELMER MICRO 10 MICRODENSITOMETER

Figure 7. [illegible]CIPAS Analysis Facilities

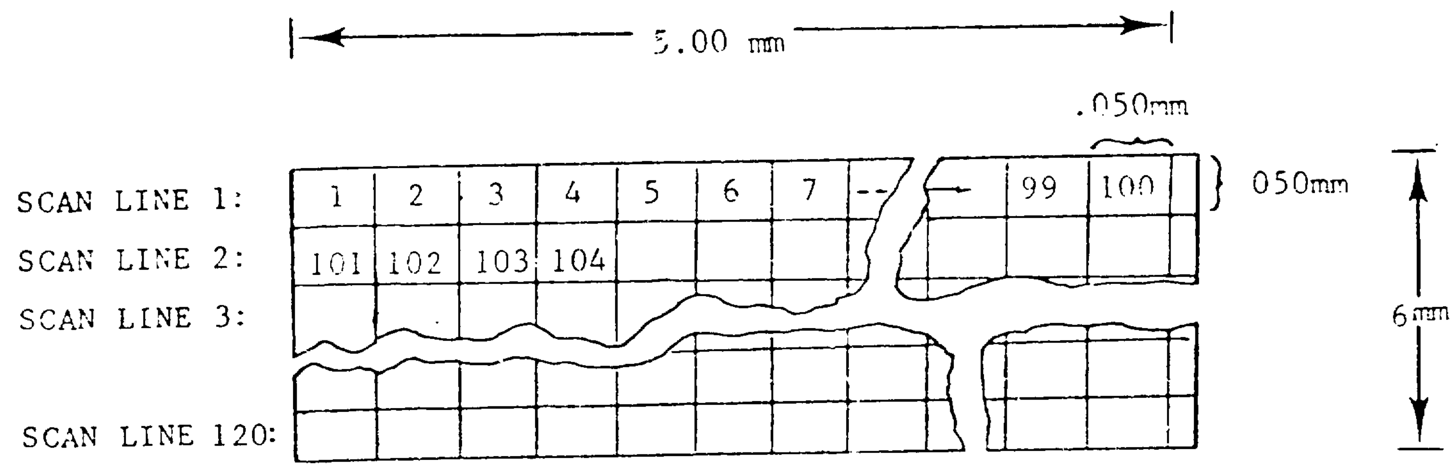


Figure 8. Microdensitometer Scan Sequence

Analysis of the image densities requires input of the sensitometric characteristics of the film. The densities of each of the 21 steps from the five sensitometer exposures processed with the images were read using the microdensitometer and recorded in an input data set. A plot illustrating the average film response measured from the set is provided in Figure 9. By measuring the slope of the straight-line portion of each function, the average value of the film contrast was determined as $\gamma = 2.96$. Although this contrast was not as high as had been determined in preliminary film tests at OTC, it was sufficient for accurate evaluation of the smoke transmission.

The computer software, CONMAP, utilizes the film sensitometry data to relate the densities read from the smoke plume or sky background image to the relative scene brightnesses that produced each density. The code then compares the relative brightness values among the smoke image areas to an average relative brightness of the sky background to provide a ratio. The computer output for each pixel is a direct ratio indicating the smoke plume apparent transmission:

$$\text{Transmission} = \frac{\text{Brightness of Smoke}}{\text{Brightness of Background}}$$

3.2.2 Output Maps

An example transmission map is presented in Figure 10. Each symbol printed on the map represents a reading taken by the microdensitometer. Since the analysis is concerned only with smoke that appears darker than the sky background, areas brighter than or equal to the average background brightness are printed as blanks. The symbols, 0 through 9, indicate transmissions analyzed from the image of 88.8 to 93.8 percent. The symbols, A through J, represent transmissions of the plume from 93.8 to 98.8 percent. A "-" indicates areas where the transmission is less than 88.8 percent. The 98.8-percent upper limit results from the variability of the sky background brightness. In this case a one-standard deviation limit was placed on the average or mean background brightness to eliminate most of the fluctuations within the sky itself.

For illustrative purposes, symbols which appear to represent a progression from dark to light when printed can provide a simulated "photograph" of the scanned image when printed as a map. This method can be used to locate

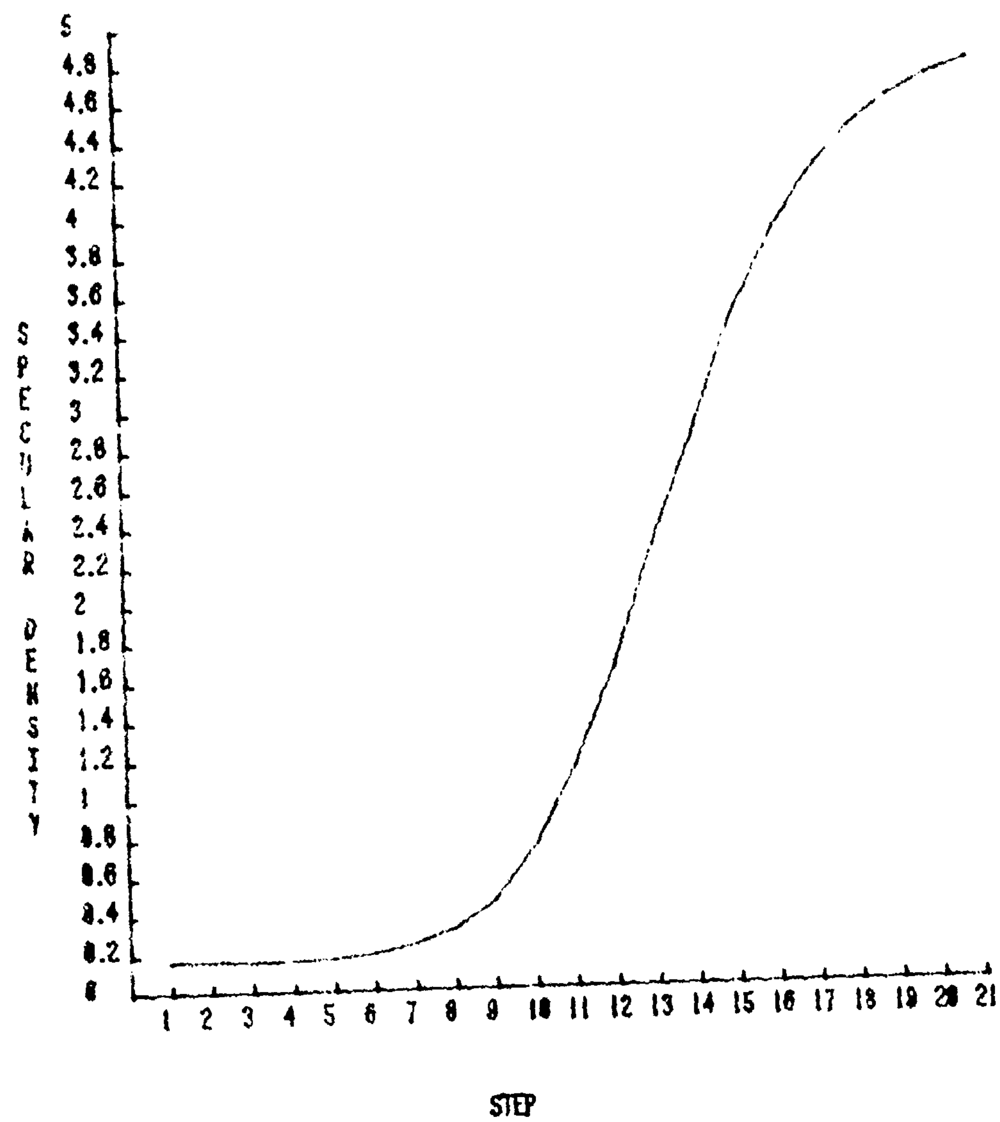


Figure 9. Technical Pan Characteristic Curve

SYMBOL	TRANSMISSION RANGE
0	0.888 * 0.893
1	0.893 * 0.898
2	0.898 * 0.903
3	0.903 * 0.908
4	0.908 * 0.913
5	0.913 * 0.918
6	0.918 * 0.923
7	0.923 * 0.928
8	0.928 * 0.933
9	0.933 * 0.938
A	0.938 * 0.943
B	0.943 * 0.948
C	0.948 * 0.953
D	0.953 * 0.958
E	0.958 * 0.963
F	0.963 * 0.968
G	0.968 * 0.973
H	0.973 * 0.978
I	0.978 * 0.983
J	0.983 * 0.988

SYMBOLS

GREY SCALE

Figure 10. Transmission Map and Grey Scale Output

specific areas of the smoke plume that are of interest. An illustration of the simulated "photograph" is shown in Figure 10. Because of format characteristiscs of the line printer used to output this grey scale map, however, the diagram is somewhat distorted. The scale of the printout is shown as 1.06 times higher than the width. Although this does not present a problem in the analysis of the average plume transmission, grey scale maps presented in the following sections are printed on a Versatec® printer/plotter that provides symmetrically scaled output.

3.3 Plume Measurements - Flight Test

Analysis of the imagery from Camera #2 has provided smoke transmission data for the C-130 flight test sequences conducted at EAFB. As previously discussed, the film from Camera #1 was improperly exposed and could not be used to accurately determine the smoke plume transmission information.

The mean transmission of the smoke plume in each flight test photograph was determined, using a statistical analysis routine, MAPSTAT. The code provides frequency distribution and mean values for a selected area of the transmission map bounded by a user specified polygon. An example output table produced by the MAPSTAT analysis of the smoke plume transmission map in Figure 10 is shown in Figure 11. The table identifies the frequency of symbols on the map at each transmission level, the total number of pixels within the smoke plume, 1272, and the average plume transmission, 96.2 percent.

Examples of the transmission frequency distribution or normalized histogram are provided in this section. A complete set of frequency distribution plots for all of the smoke test runs is provided in Appendix B. The data is organized to present the transmission data from each photograph during a single fly-by on one figure. The plots were normalized to provide the relative frequency of each transmission value within the smoke plume. Figure 12 illustrates the frequency distributions det d from Frames 2, 3, and 4 on Run #5 (Overhead pass, Flight Idle power). The distribution of transmission values for Frames 2 and 3 are very similar. The overall average plume transmission for each measure between 97.5 and 98.5 percent within a single cell (bin) and, therefore, the distribution appears as a single line approaching 1.0 or 100 percent.

FRAME A4-5

SYMBOL	TRANSMISSION RANGE		#
Ø	Ø.885 :	Ø.89Ø	Ø
1	Ø.89Ø :	Ø.895	Ø
2	Ø.895 :	Ø.9ØØ	Ø
3	Ø.9ØØ :	Ø.9Ø5	Ø
4	Ø.9Ø5 :	Ø.91Ø	1
5	Ø.91Ø :	Ø.915	1
6	Ø.915 :	Ø.92Ø	1
7	Ø.92Ø :	Ø.925	4
8	Ø.925 :	Ø.93Ø	8
9	Ø.93Ø :	Ø.935	19
A	Ø.935 :	Ø.94Ø	29
B	Ø.94Ø :	Ø.945	79
C	Ø.945 :	Ø.95Ø	98
D	Ø.95Ø :	Ø.955	129
E	Ø.955 :	Ø.96Ø	168
F	Ø.96Ø :	Ø.965	164
G	Ø.965 :	Ø.97Ø	192
H	Ø.97Ø :	Ø.975	115
I	Ø.975 :	Ø.98Ø	144
J	Ø.98Ø :	Ø.985	12Ø

****************MAP STATISTICS**************

NUMBER OF POINTS GREATER THAN Ø.885: 25
NUMBER OF POINTS BETWEEN LIMITS: 1272 ←
NUMBER OF POINTS LESS THAN Ø.985: Ø
NUMBER OF POINTS EQUAL TO THE BACKGROUND : 826

TRANSMISSION MEAN Ø.9622 ←
TRANSMISSION STD DEV Ø.Ø133

TRANSMISSION LINE-BY-LINE STATISTICS

LINE	DATA	MEAN	STD DEV
2Ø	25	Ø.9545	Ø.Ø2Ø7
21	29	Ø.9558	Ø.Ø171
22	29	Ø.9622	Ø.Ø162
23	32	Ø.9517	Ø.Ø155
24	33	Ø.9617	Ø.Ø134
25	37	Ø.9667	Ø.Ø111
26	36	Ø.9636	Ø.Ø122
27	41	Ø.9655	Ø.Ø114
28	4Ø	Ø.9613	Ø.Ø11[illegible]
29	42	Ø.9611	Ø.Ø121
3Ø	42	Ø.9596	Ø.Ø114
31	42	Ø.961Ø	Ø.Ø11Ø
32	43	Ø.962Ø	Ø.Ø1Ø2
33	41	Ø.9627	Ø.Ø119
34	36	Ø.9554	Ø.Ø11Ø
35	33	Ø.9643	Ø.Ø115
36	29	Ø.9613	Ø.Ø122
37	32	Ø.9698	Ø.Ø1ØØ
38	32	Ø.9573	Ø.Ø148
39	31	Ø.9556	Ø.Ø114
4Ø	28	Ø.9538	Ø.Ø112
41	28	Ø.9546	Ø.Ø128
42	32	Ø.9591	Ø.Ø111
43	31	Ø.9596	Ø.Ø132
44	33	Ø.965Ø	Ø.Ø126
45	31	Ø.9625	Ø.Ø12Ø
46	3Ø	Ø.9637	Ø.Ø117
47	27	Ø.9551	Ø.Ø132
48	29	Ø.9573	Ø.Ø152
49	3Ø	Ø.9637	Ø.Ø145
5Ø	31	Ø.95Ø7	Ø.Ø14Ø
51	3Ø	Ø.9625	Ø.Ø164
52	31	Ø.9623	Ø.Ø131
53	31	Ø.9662	Ø.Ø111
54	32	Ø.9673	Ø.ØØ98
55	29	Ø.968Ø	Ø.Ø111
56	27	Ø.9692	Ø.Ø1Ø5
57	28	Ø.9721	Ø.ØØ94
58	29	Ø.9722	Ø.ØØ83

Figure 11. MAPSTAT Output Tables

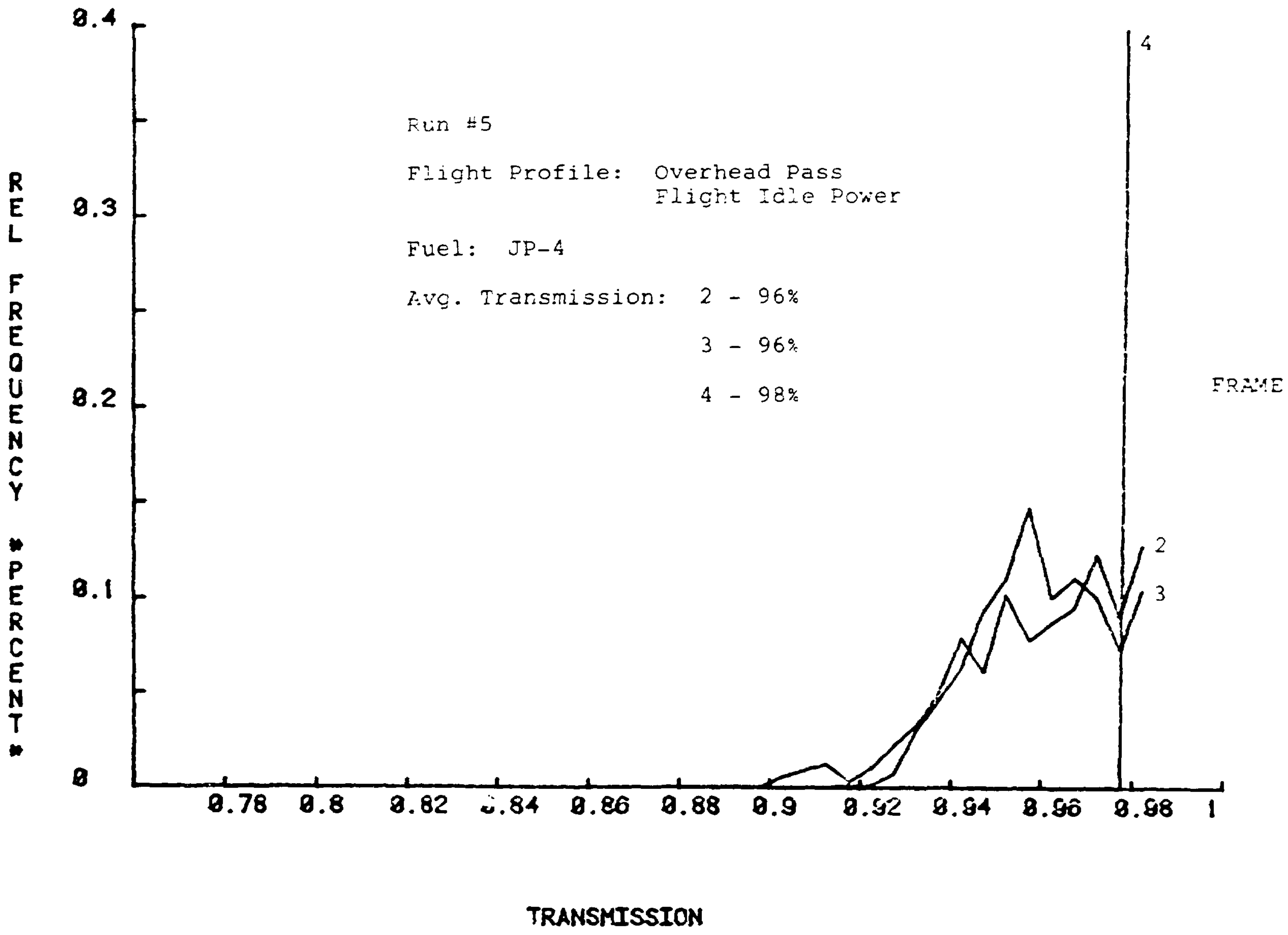


Figure 12. Relative Transmission Distribution - Run #5

A grey scale map series of Run #5 is provided in Figure 13. The grey level in each map corresponds to various smoke transmission levels as indicated by the calibrated scale on the left side of the figure. The white areas of the map indicate areas of 98.5 percent transmission or higher.

The frequency distributions for the smoke transmission from Run #6 (Overhead pass, Approach power) are shown in Figure 14. A grey scale map sequence for this run is provided in Figure 15. The average transmission of the plume during this run ranges from 96 to 97.6 percent with portions of the plume at 89% transmission. As illustrated by the grey scale maps, the definition of a single plume is difficult since the smoke from each engine accumulated inconsistently. The overall plume is generated by 3 to 4 engines in this sequence, however, the contribution of smoke from each engine is shown to vary.

The smoke produced by the C-130 aircraft during Run #9 (Overhead pass, Takeoff power) is plotted in Figure 16. The average plume transmission in Frame #3 was calculated as 95.6 percent, whereas the smoke in other frames from the run average above 97 percent. The distribution of transmission values throughout the plume is varied for each frame, however, Frame #3 illustrates that either the smoke production was increased (i.e. throttle change) or the dispersion of smoke was altered by atmospheric conditions. This is illustrated in the grey scale map sequence in Figure 17. Examination of the smoke in Frame #3 and Frame #4 shows the development of a dense smoke patch. As the sequence continues to Frame #7 the higher viewing aspect angles cause the transmission of the plume to approach 100 percent.

The transmission data from Run #13 (Parallel pass, Cruise power) is plotted in Figure 18 and mapped in Figure 19. This is an example of a run where the measured smoke was minimal. Transmission averages of 97.8 and 97.9 percent for Frames 5 and 6 were found with no measurable smoke in Frame 7 and 8. The background "noise" illustrated at the top of Frame #8 results from variation in the background brightness within the frame. While the background is measured at these areas within the frame, only the average value is used in reducing the data. This method does not account for systematic variations in the background level. A more sophisticated algorithm could be developed that would include the systematic sky background variation, however, this is only significant when the target is at a close range to the measurement camera or a large variation in background level is present for other reasons.

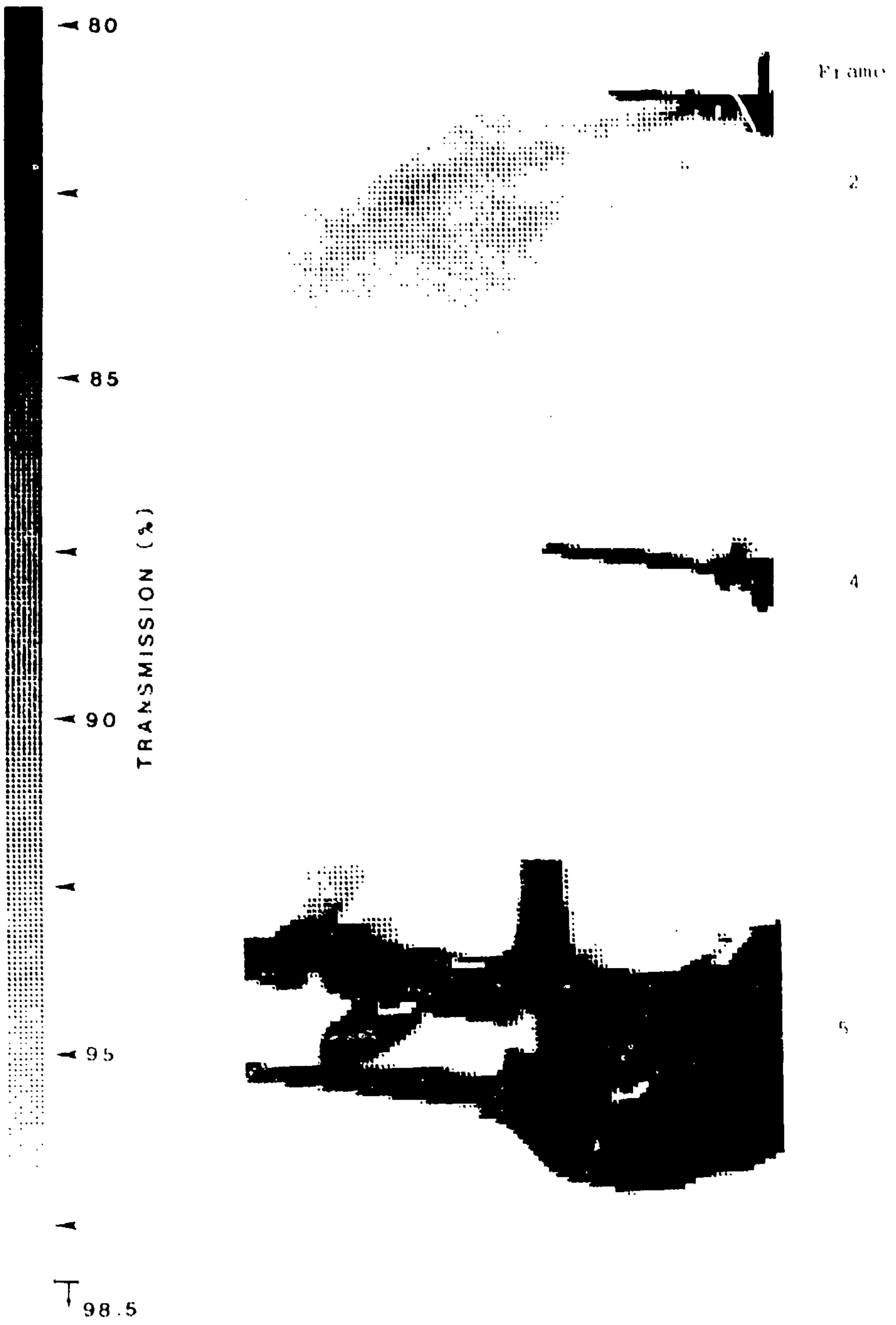


Figure 13. Grey Scale Maps - Run Number 5

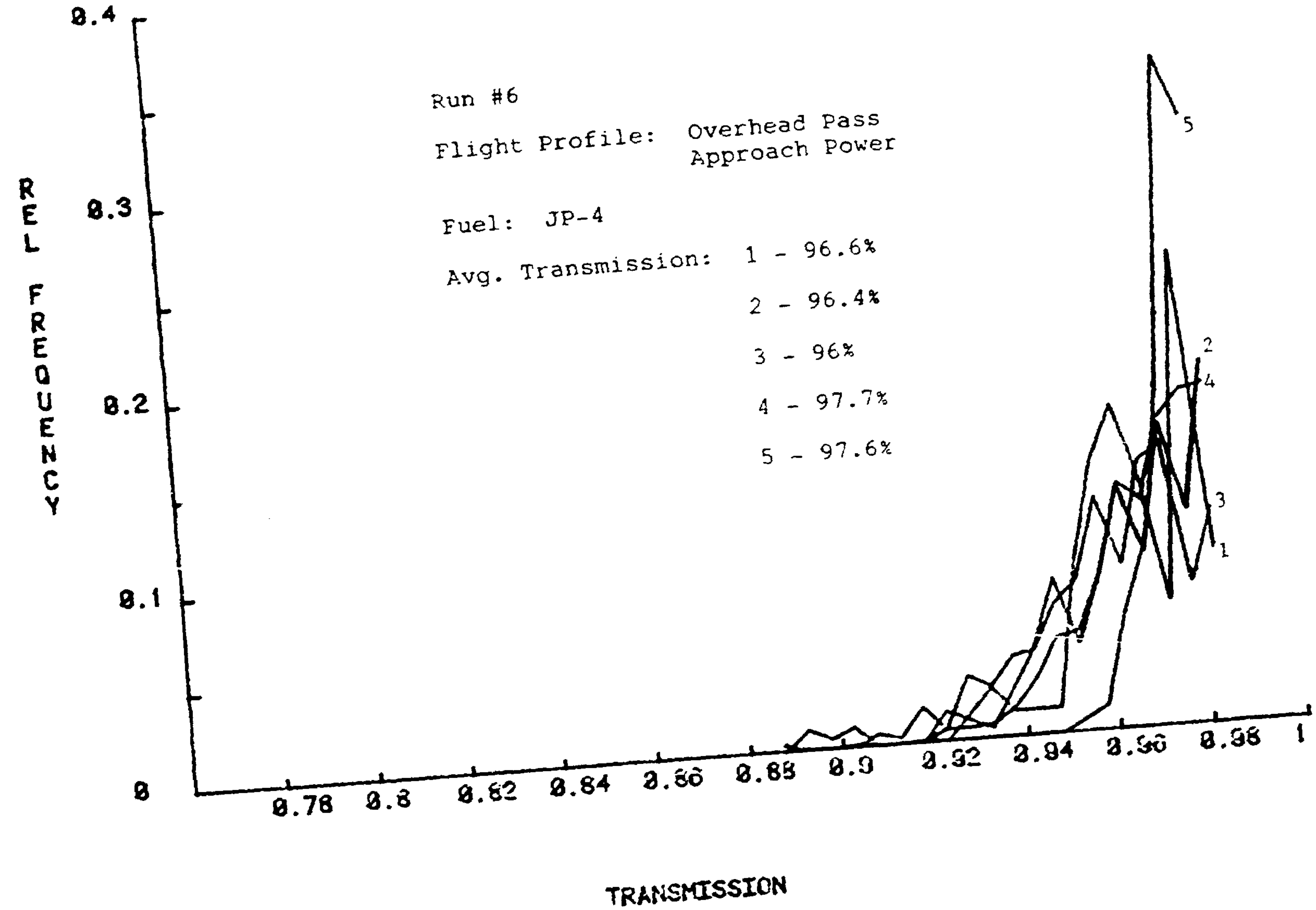


Figure 14. Relative Transmission Distribution - Run #6

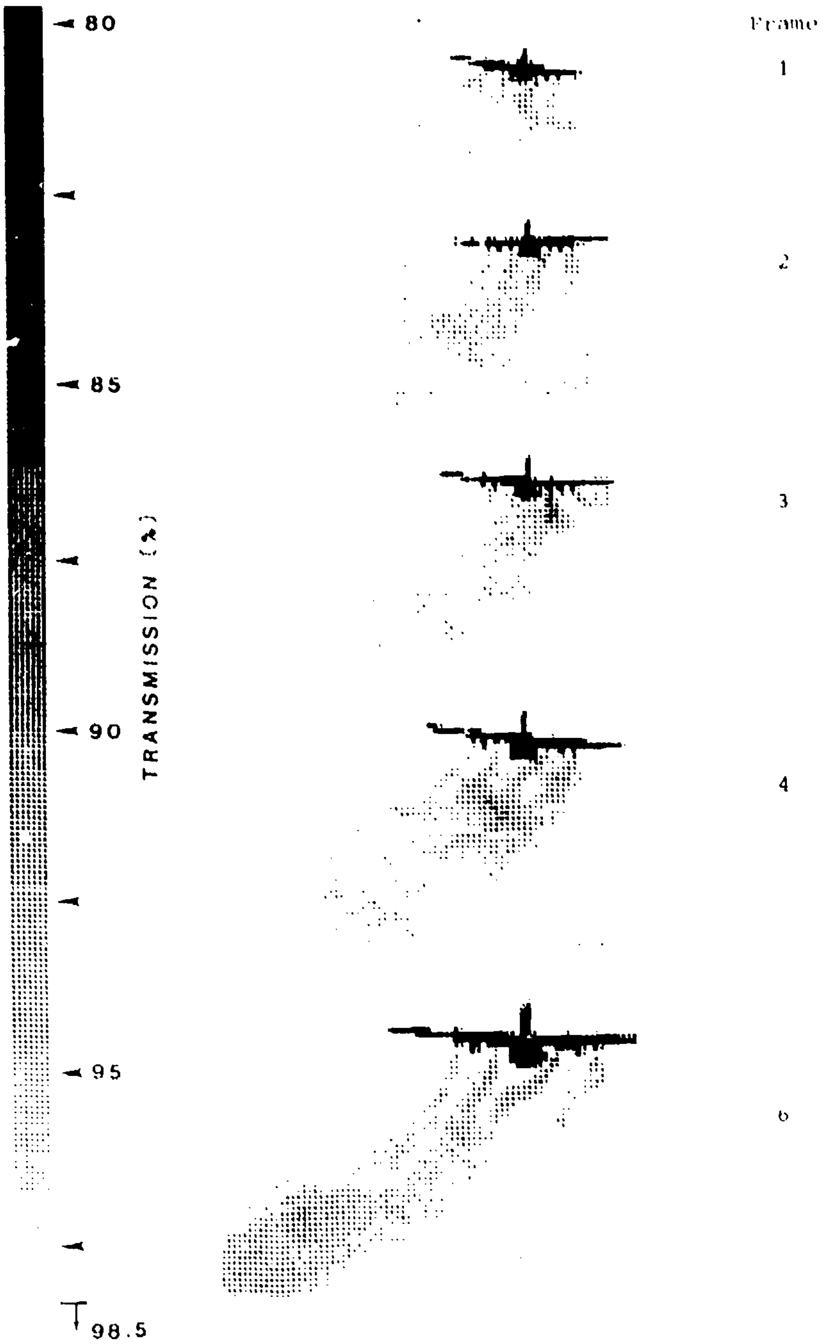


Figure 15. Grey Scale Maps - Run Number 6

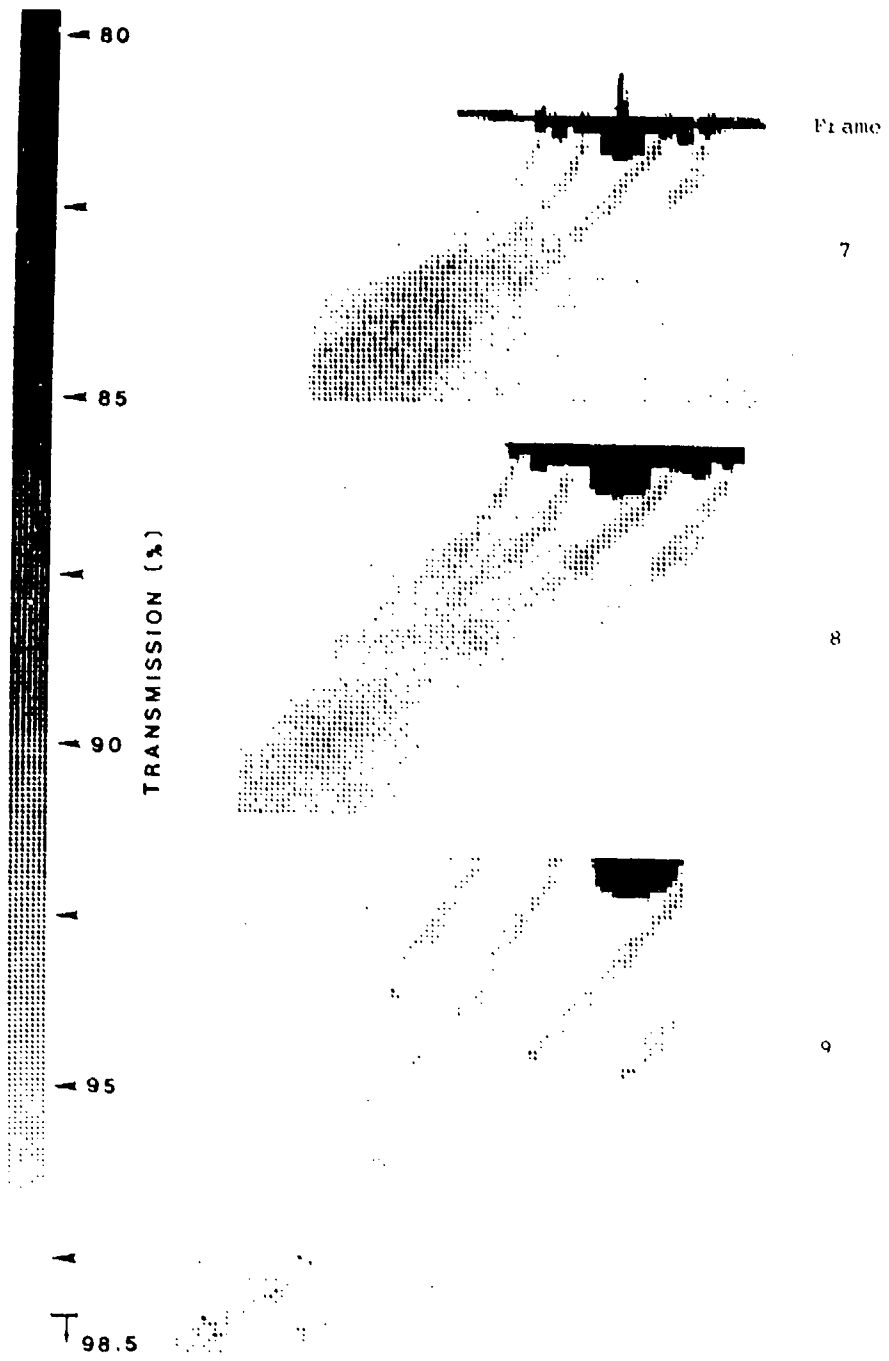


Figure 15. Grey Scale Maps - Run Number 6 (Concluded)

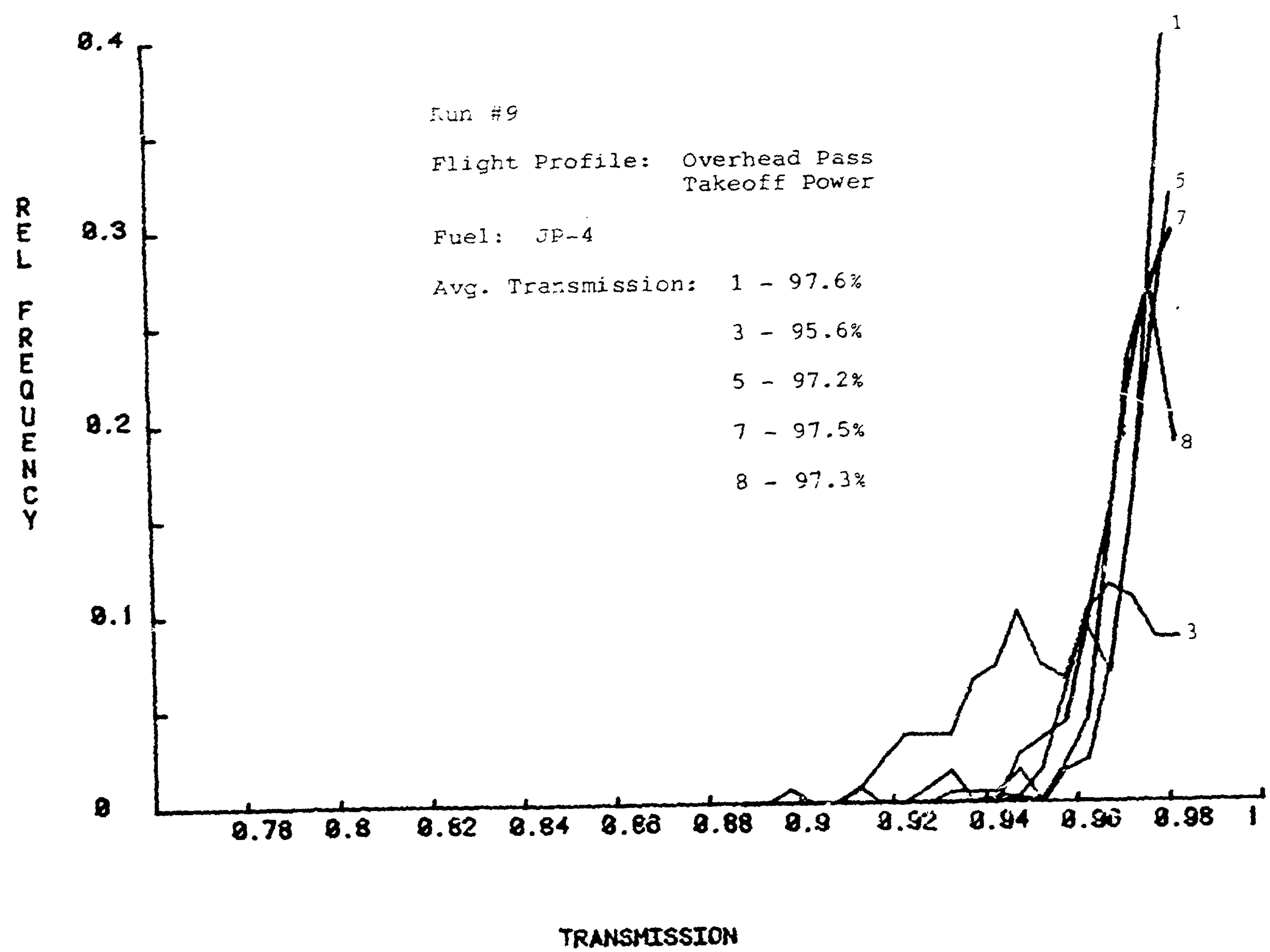


Figure 16. Relative Transmission Distribution - Run Number 9

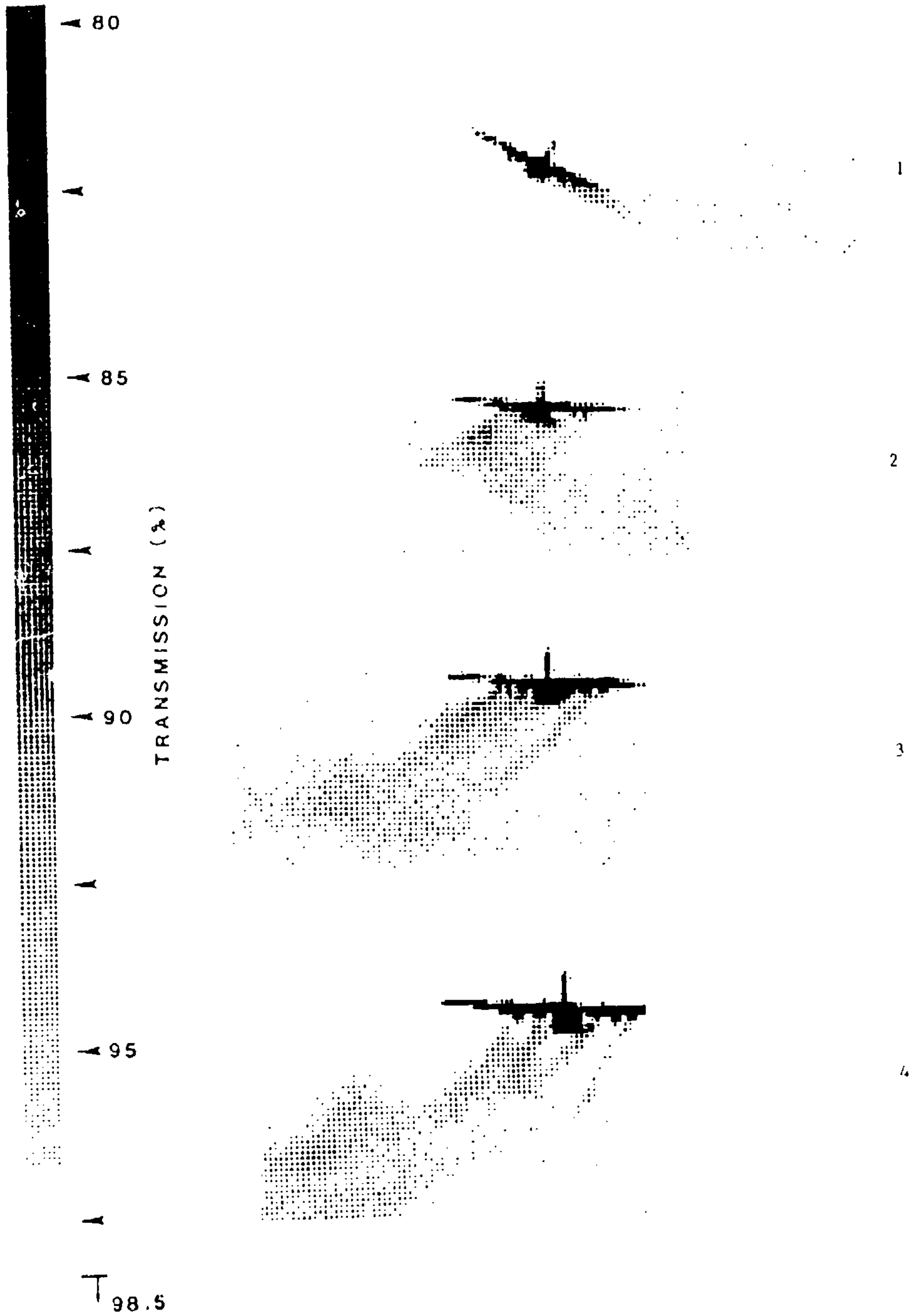


Figure 17. Grey Scale Maps - Run Number 9

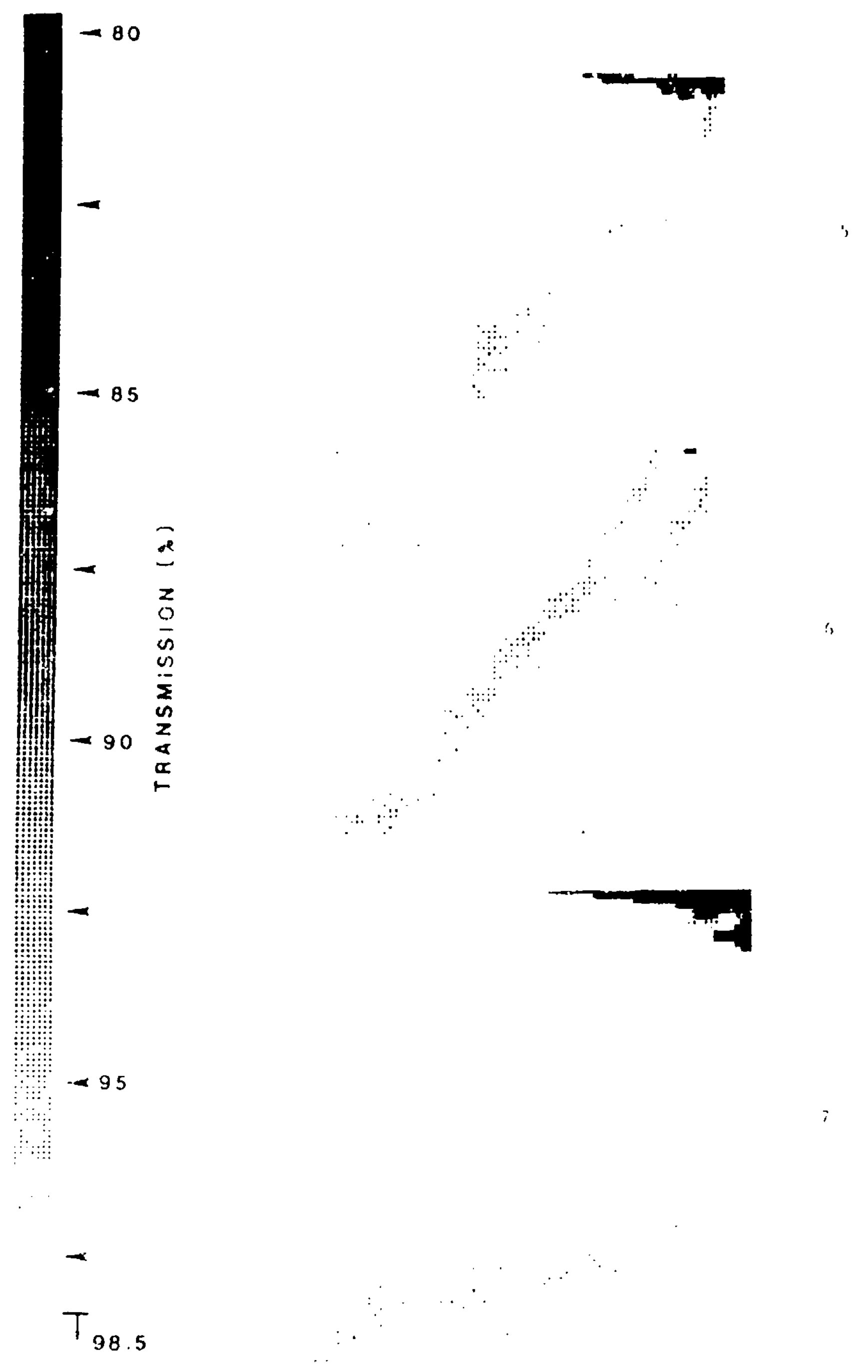


Figure 17. Grey Scale Maps - Run Number 9 (Concluded)

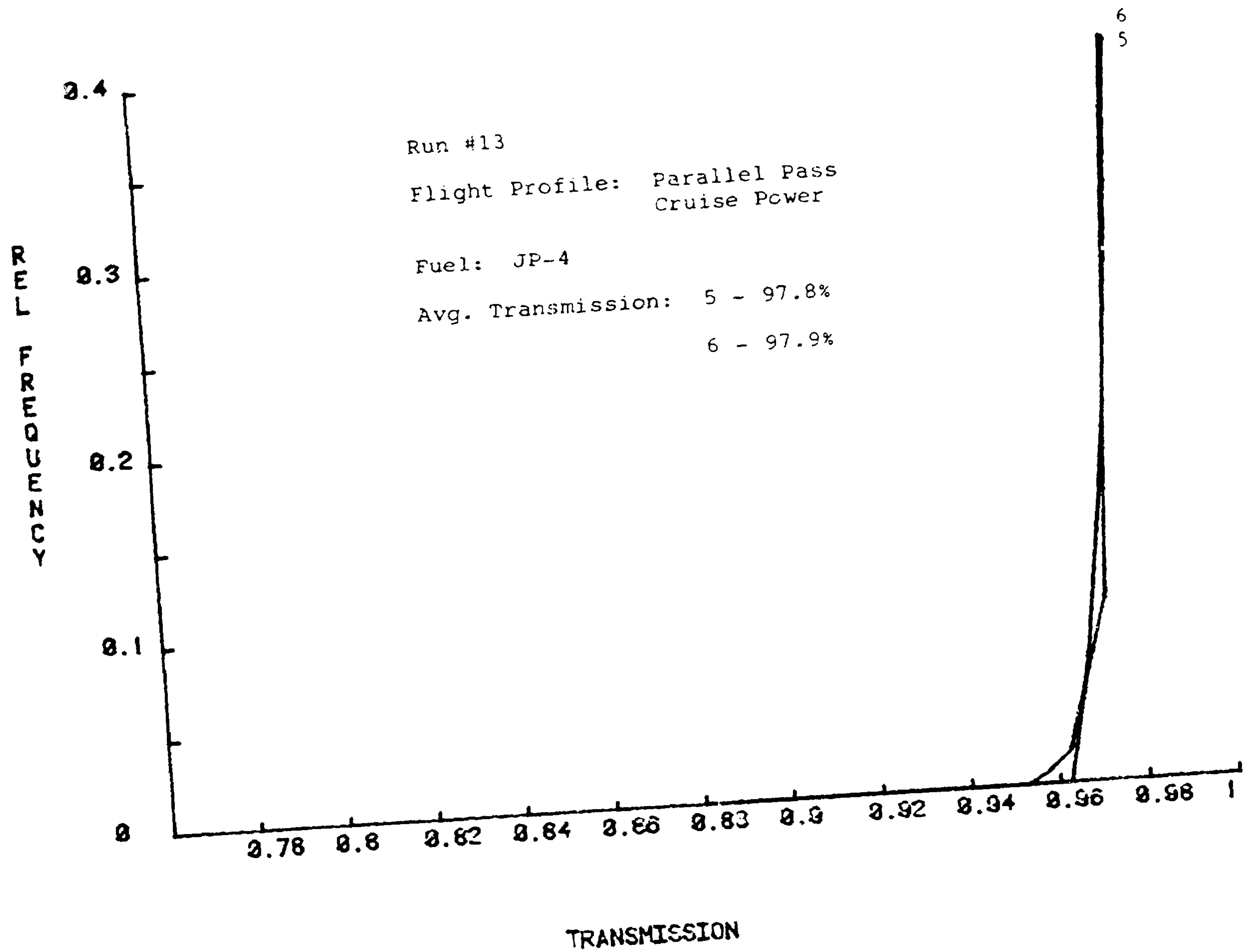


Figure 18. Relative Transmission Distribution - Run #13

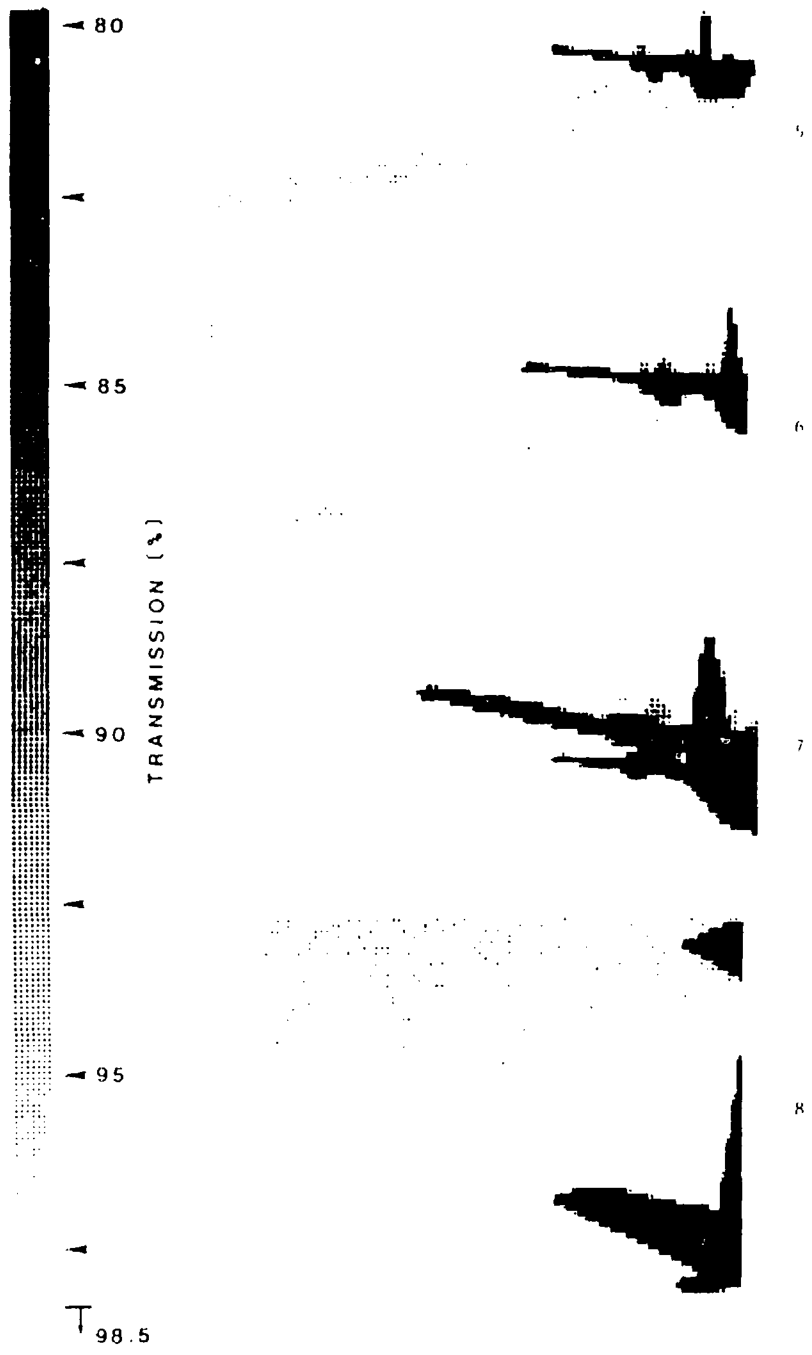


Figure 19. Grey Scale Maps -Run Number 13

The next example is Run #15 (Parallel pass, Takeoff power). The relative frequency plot of smoke transmission is provided in Figure 20 and the grey scale maps in Figure 21. In Frame #1, the smoke is blocked by the aircraft and, therefore, no transmission data was available. Dark plume transmission values found in Frame #2 were due to the radial plume viewing aspect. As the sequence progressed, the viewing angle approached a perpendicular aspect and no smoke could be measured.

3.4 Plume Measurement - Ground tests

Photographic data was collected during ground tests to determine the plume transmission from a perpendicular aspect and relate the values to smoke number readings from a smoke meter. The collection of valid photographic information, however, required a sky background of uniform brightnesses. Transmission data could not be generated from the photographs because the sky background viewed through the plume was near the horizon, cloudy and non-uniform. The nonuniform background within the field-of-view of the camera varied enough that differences in measured brightnesses caused by the smoke could not be distinguished from background changes.

Successful readings of opacity by the observers, smoke numbers (from DDA/GM tests using the smoke meter), and the engine power for each test run were documented. The observers were able to evaluate the plume opacity (with some difficulty) by viewing a selected area and observing the brightness change due to the turbulent plume. By constant observation of the plume, much more information was available to the observers than to the instantaneous film record. Figure 22 illustrates the location of the two observers and the over-all ground test setup. The photograph was taken from the same location as the data recording camera.

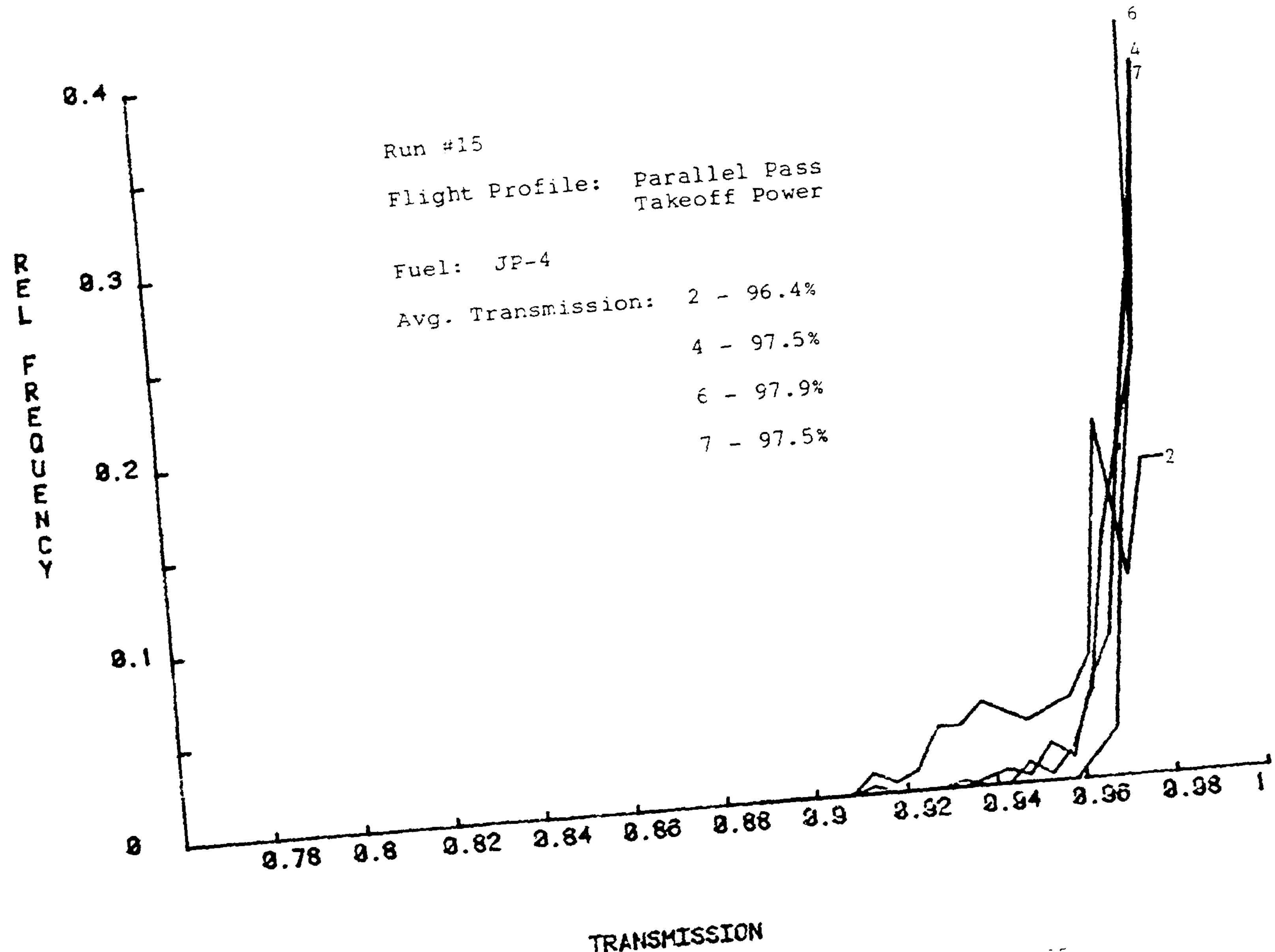


Figure 20. Relative Transmission Distribution - Run Number 15

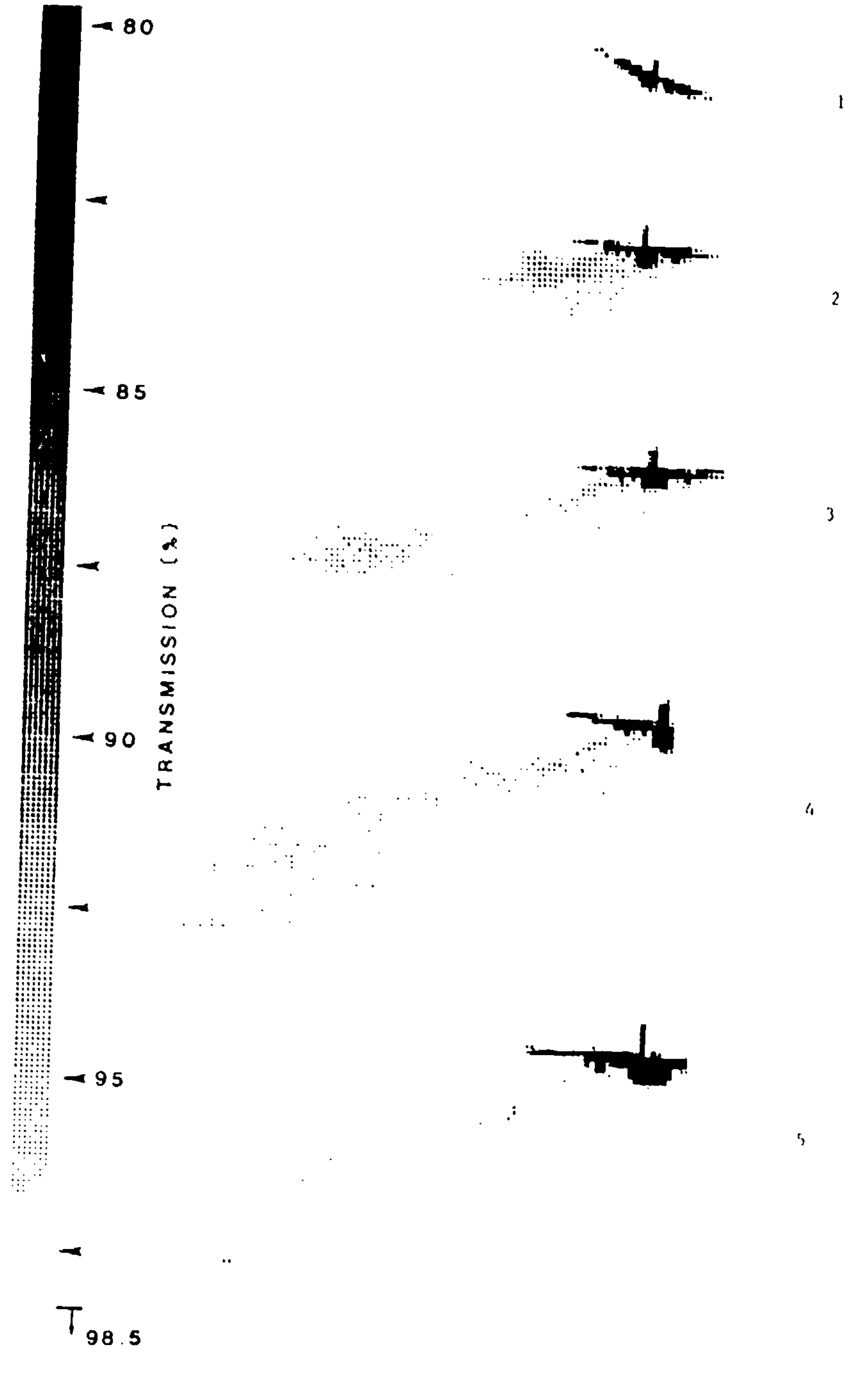


Figure 21. Grey Scale Maps - Run Number 15

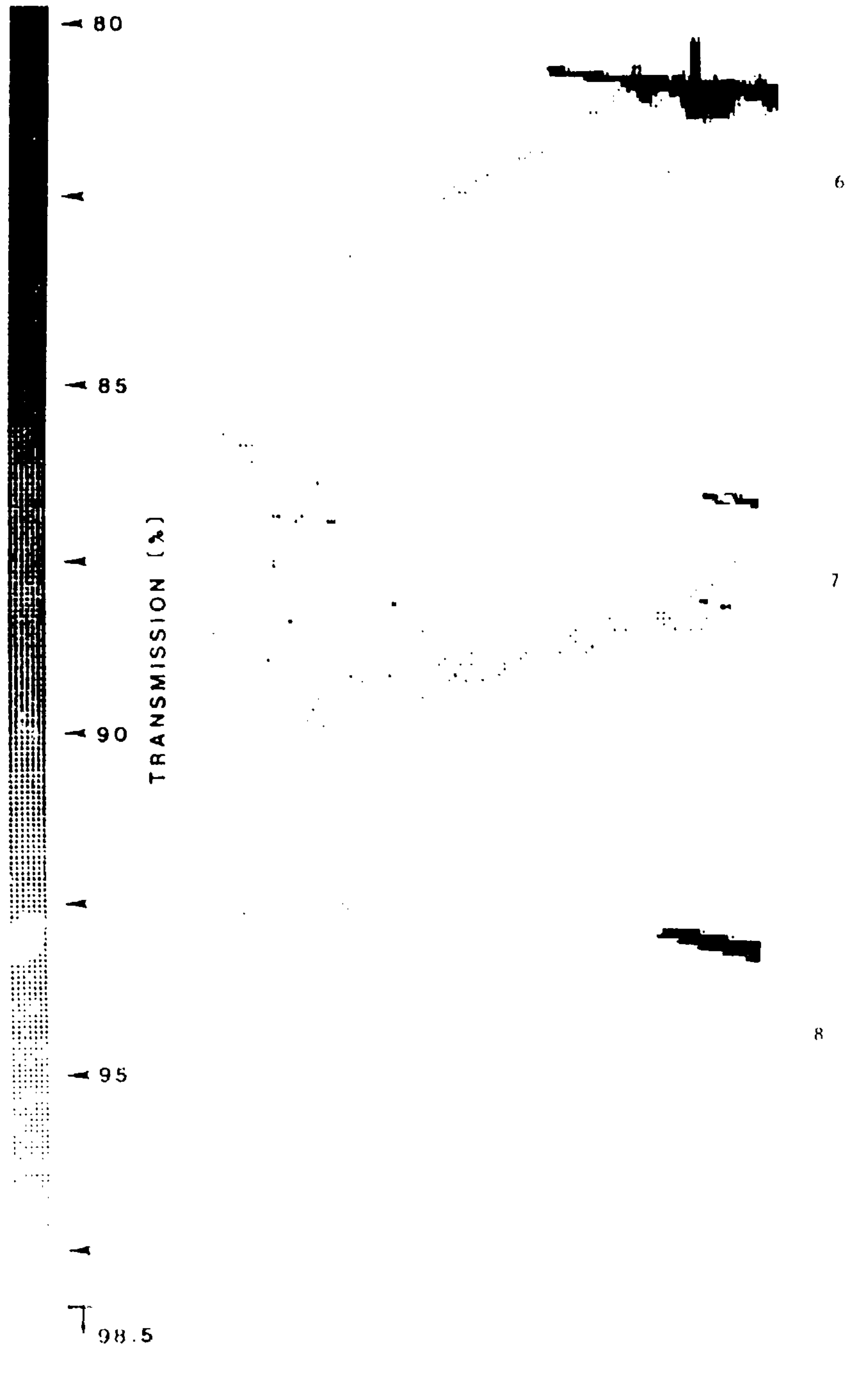


Figure 2 . Grey Scale Maps - Run Number 15 (Concluded)

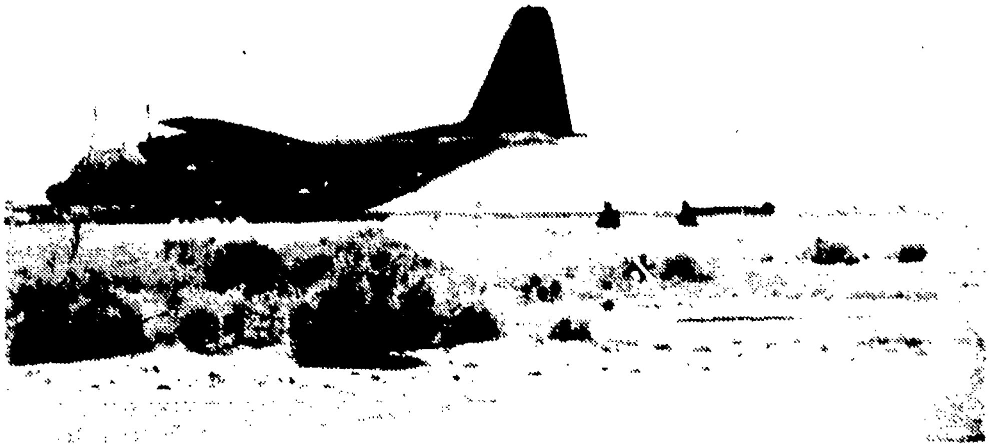


Figure 22. Ground Runup Plume Observation

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SECTION IV

4.0 TRANSMISSION MEASUREMENT COMPARISONS

The smoke plume data collected photographically is compared to the data documented by the two certified visual emission readers in this section. The photographic data is also related to the measured smoke number of the engine power setting/fuel combination. Table 3 summarizes smoke meter measurements made during the ground runups. The data was utilized for comparison to the flight test smoke transmission values. As previously discussed, the tests compare the smoke produced by JP-4 and JP-5. The smoke numbers increase from the 40 to 50 range with JP-4 to the 50 to 60 range with JP-5. The differences between the fuel flow of the ground tests and the flight test fuel flow are not taken into account in the data comparisons made in this section. The inflight fuel consumption for the climb and cruise settings were 10 - 20 percent higher than the ground runup tests.

TABLE 3. GROUND RUNUP SMOKE NUMBERS

Power Setting	Smoke #	GND Test Fuel Flow (LB/HR)	Flight Test Fuel Flow (LB/HR)
Approach & Land (JP-4)	43	875	1000 - 1100
Flt. Idle (JP-4)	44	800	600 - 700
Cruise (JP-4)	50	1350	1500
T/O & Climb (JP-4)	51	1700	2000 - 2200
Approach (JP-5)	54	900	1000 - 1100
Cruise (JP-5)	60	1400	1600
Takeoff (JP-5)	60	1800	2000 - 2100

4.1 Photographic Versus Visual

Comparison of the smoke plume transmission data to the values recorded by the visual emission observers involved examination of the darkest areas of the plume rather than the overall average. On each run the observers attempt to view the darkest area of the plume and record the "opacity" (100-percent Transmission) of this area. A problem in representing this visual estimation procedure in the analysis of the photographic data is selecting the plume size that the observer views for generation of data. The angular resolution of the eye is approximately 1/60 degree (1 arc minute); however, the evaluation of opacity by the eye would not be made over such a small area. A more realistic assumption would be that the observers averaged over an angular area on the order of five to fifteen arc minutes in the darkest part of the plume.

The resolution of the grey scale maps is similar to that of the eye in that each pixel is a square with 1.72 arc minute sides. To reduce the photographic data to a value representing the darkest visual area, a standard data analysis format was developed. First, it was determined that the area of 26 pixels from the map equals the area of a circle with an angular diameter of 10 arc minutes. This is independent of the range between the target and measurement camera. The next step was to represent the plume transmission data from each frame as a cumulative distribution. The data from Run #6 is plotted in Figure 23 for illustration. The entire sequence of runs is contained in Appendix C. These plots illustrate the relative contribution of each transmission value to the overall smoke plume by examination of the slope of the curve.

The transmission value at 10 arc minutes size or after 26 pixels was found from the plots for comparison to the visual observer data. This value approximates the average transmission of the plume over a 5 to 15 arc minute size area. The cumulative frequency level corresponding to 26 pixels varies between frames since the size (total number of pixels) of the plume varies. The transmission values at 10 arc minutes are identified on each cumulative plot in Appendix C and in Figure 23.

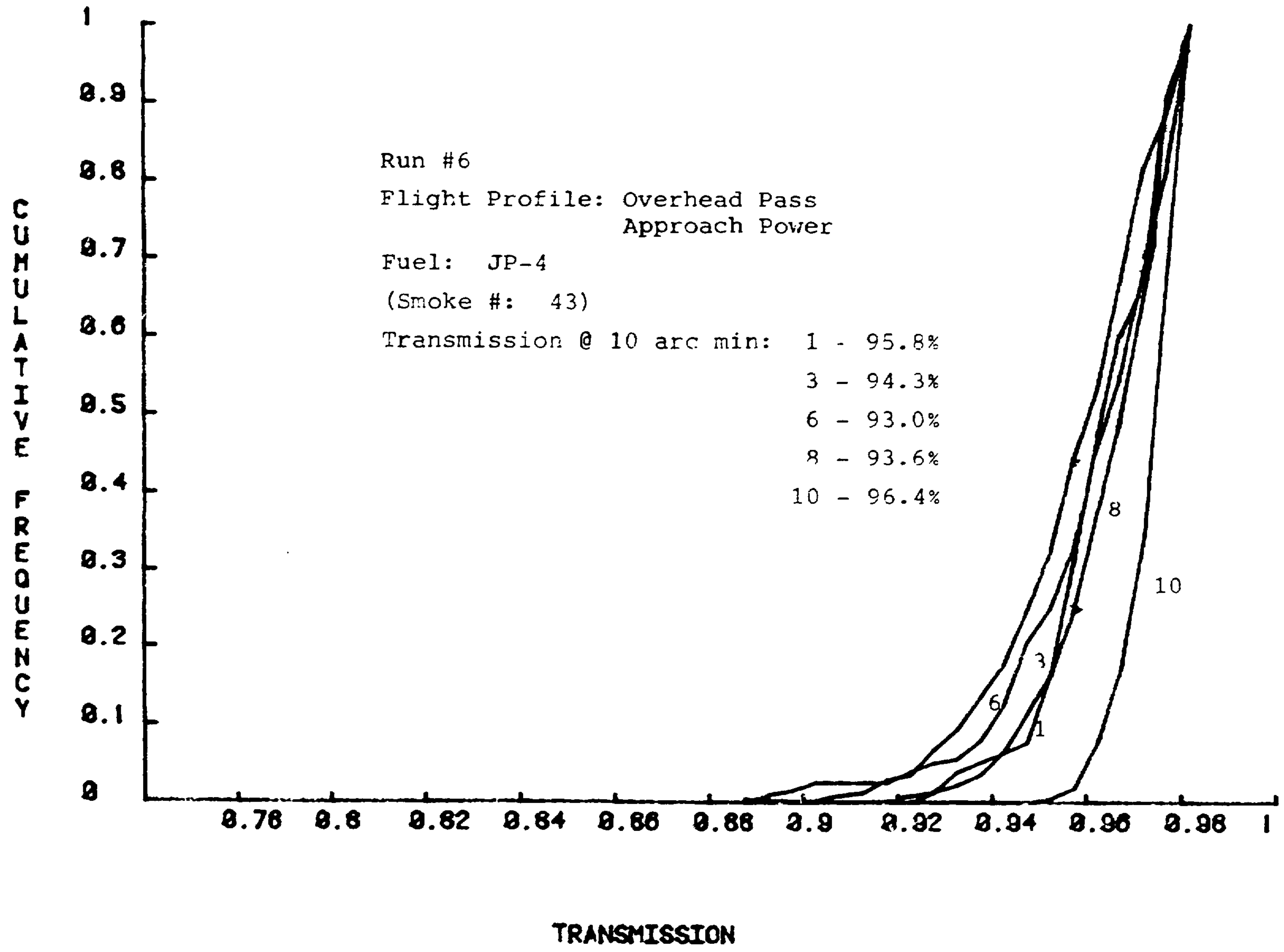
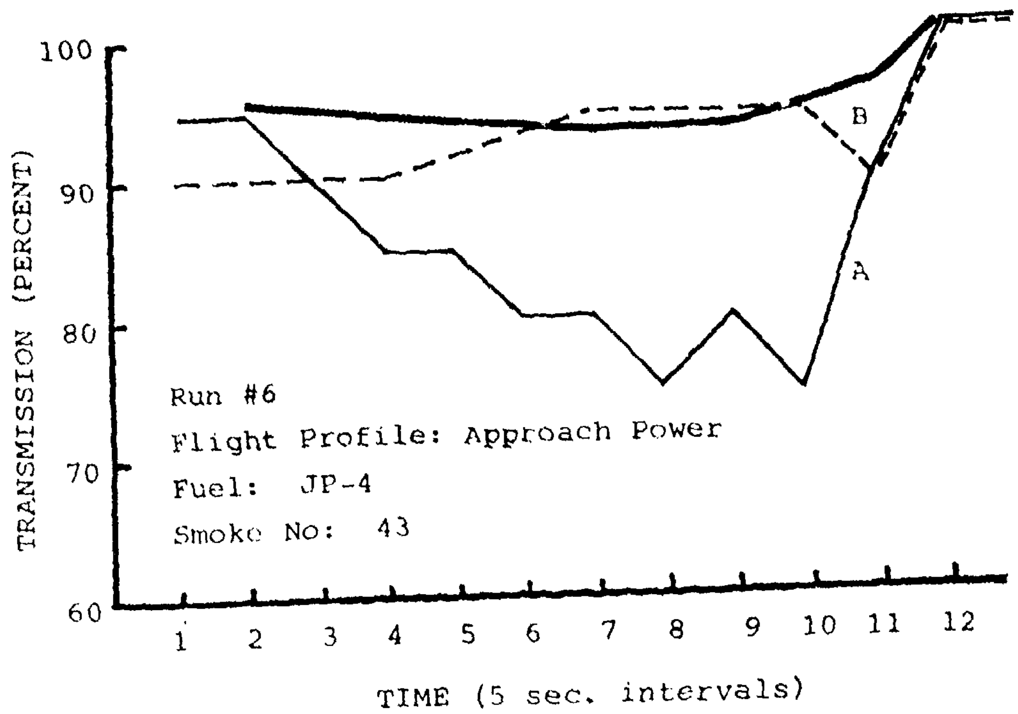


Figure 23. Transmission Cumulative Frequency for Run Number 6

Comparison of the photographic and observer transmission data was accomplished by plotting the transmission values as a function of time. The transmission values from the observers were obtained from the opacity values that were documented in OEHL Report No. 80-27. Figure 24 provides an example for Runs #6 and #7. The remaining plots are supplied in Appendix D. The thin solid line represents data recorded by Observer A (Vlasko), the dashed line represents Observer B (Stevens), and the heavy solid line represents the photographic data of the darkest area of the plume (10 arc minutes). Because of the separate viewing positions of the two observers and the camera, the viewing aspects would be expected to differ significantly during the last two to three 5-second intervals of the run (approximately 5,000 ft. range). Before that time, however, all tranmission data should be the same.

Although some similar trends can be seen by examining the photographic data and the observer data, differences between all three sources are evident. Figure 25 is a scatter diagram illustrating the transmission data measured photographically versus the observer readings. The data was plotted at each five second interval on the plots in Appendix C. Values were interpolated for time points where no readings were made. The dashed line illustrates exact correlation. The scatter of the data in the figure shows little correlation between the three data sources. Most of the values throughout the tests for Observer A range from 70 to 90 percent. The data for Obvserver B ranges primarily between 90 and 100 percent. The photographic data, however, ranges primarily between 80 and 100 percent. Although there are many problems related to the collection of good photographic data, the transmission of the plume at each pixel on the map is accurate at least within ±2 standard deviations of the background brightness readings (using a 95 percent confidence level). The accuracy, therefore, in the transmission of each pixel is estimated to be better than ±3 percent transmission. The accuracy (standard deviation) of the average or 10 arc minute transmission values is considerably better. The choices of the method used to combine each value within a smoke plume to produce a single transmission value could introduce systematic errors in relating the photographic data to the observer readings.

A.



B.

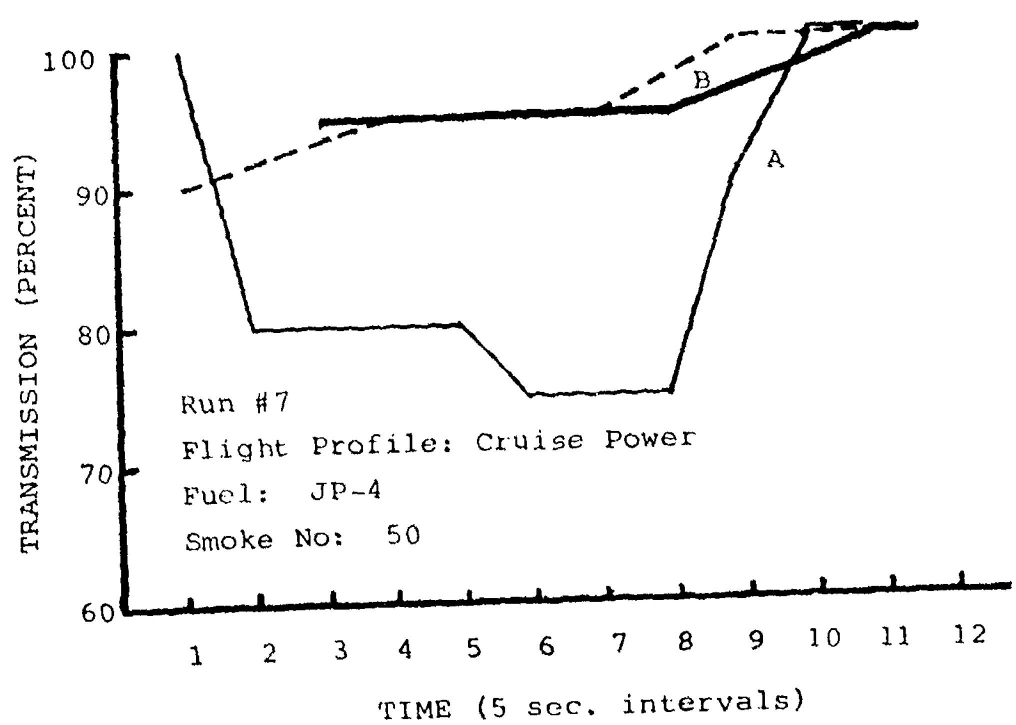


Figure 24. Transmission Data for Runs 6 and 7

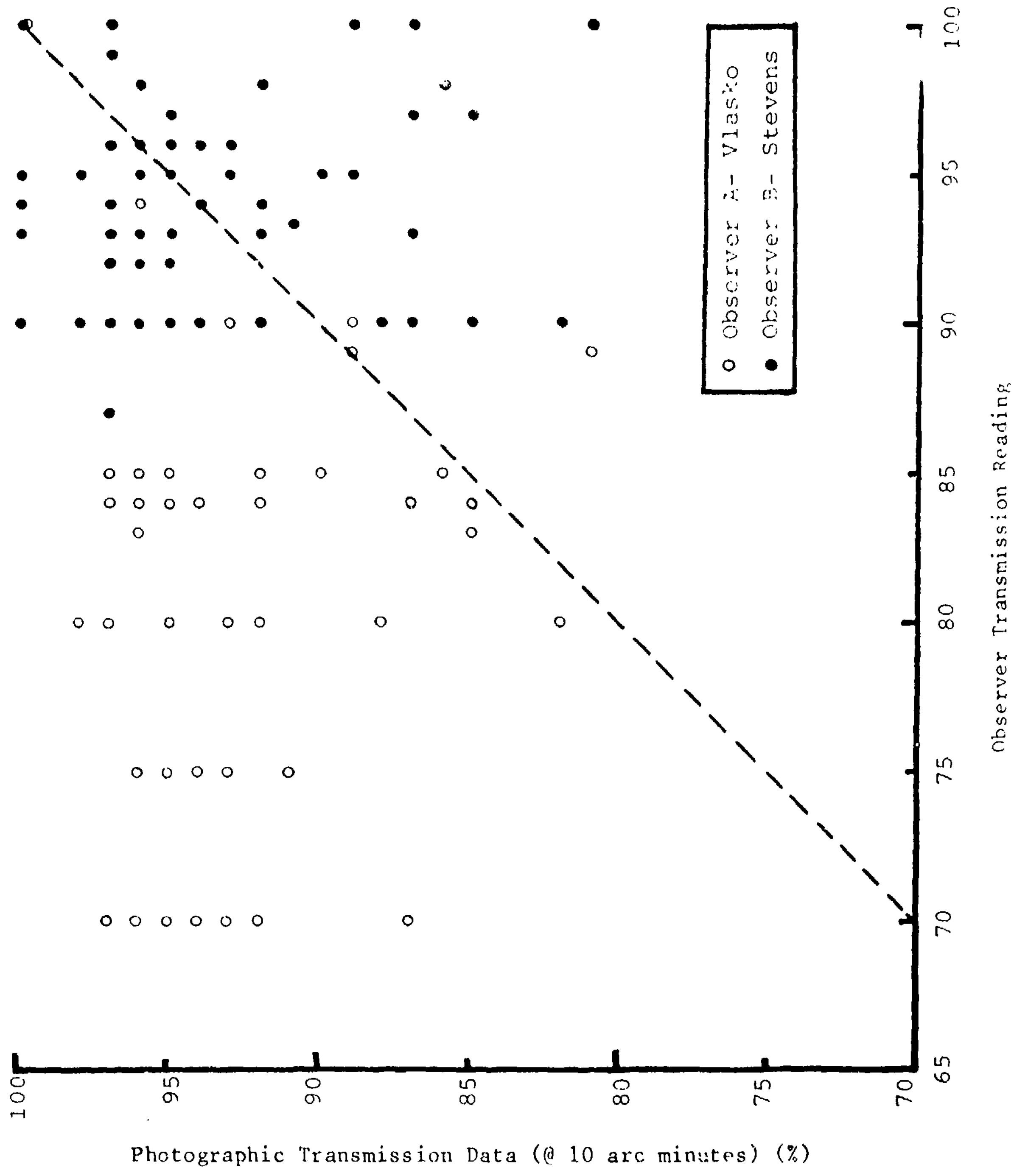


Figure 25. Photographic Versus Observer Data

4.2 Photographic Versus Smoke Number

Comparison of the photographic measurements of the smoke plume transmissions to the Smoke Numbers at each power setting required the viewing aspect of the plume to be taken into account. To simplify the task of evaluating the exact viewing angles of each plume photograph, the transmission data was grouped as a function of the range to the aircraft and the viewing aspect was assumed to be the same within each group. The approximate slant range of the aircraft from each frame was determined by measurement of the wingspan from the photographic image. Table 4 provides a summary of the average plume transmission for several range groups. The Smoke Numbers are based upon the values determined from the ground runups for one engine with the specified power setting and fuel used in each run.

The average plume transmission versus Smoke Number for ranges from 4,000 to 20,500 ft. is plotted in Figure 26. The viewing elevation from the plume axis for these slant ranges varies from 1° to 7° while the viewing azimuth varies from 0° to 14°. The data from the closer ranges were not plotted since the viewing aspect is at much higher angles. The dashed lines on the diagram illustrate the upper and lower boundaries of the data. As illustrated by this envelope, the variability of the average transmission increases with an increase of the Smoke Number from 43 to 60 and precludes significant correlation between the transmission and Smoke Number.

A threshold for average transmission corresponding to the observer's threshold of visibility was made by examination of the photo/observer plots in Appendix D. Observer A identified the plume as invisible at the 97.5 to 98.5 percent transmission. Selecting an average transmission of 98 percent as the threshold of visibility in Figure 26, the upper and lower boundaries of the plotted data can be used to provide Smoke Numbers for the visible/invisible plume. The data, however, relates the Smoke Number setting of a single engine to the transmission of the plume measured from four engines. The lower boundary of the data envelope reaches 98 percent at a Smoke Number of 33 while the upper boundary corresponds to a Smoke Number of 48.

TABLE 4. AVERAGE TRANSMISSION VERSUS SLANT RANGE

	RUN NUMBER																							
	5	6	7	8	9		11	12	13	14	15	16		18		20	21	22	23	24	25	26	27	28
SMOKE NUMBER →	44	43	50	51	51		44	43	50	51	51	54		54		60	60	60	54	60	54/43	60/51	60/51	60/51
SLANT RANGE (KFT) 16.0 - 20.5		96.0		97.7								97.8												
13.0 - 16.0	96	96.4	96.5		97.6		97	96.5		97.5	96.4			96.1		97.6			97.1		95.1	93.5	96.2	
10.0 - 13.0	98	97.7		97.8	95.6					96.5	97.5						96	96.3	95.4	92.6	95.1	94		96.9
7.0 - 10.0			96.4		97.2		97.3	96.5			97.9					96.6	96	97.1	94.4					
4.0 - 7.0			96.7	97	97.5			97.1	97.8	97.5	97.5	97.8		95.4		97.4			93.7	96.5	95.9	94.5		97.4
1.0 - 4.0			92.3	97.2	97.3		97.3	97.7	97.9	96.9		97.1		96.2		95.6			91.5	95	99.3	94.3		97.8

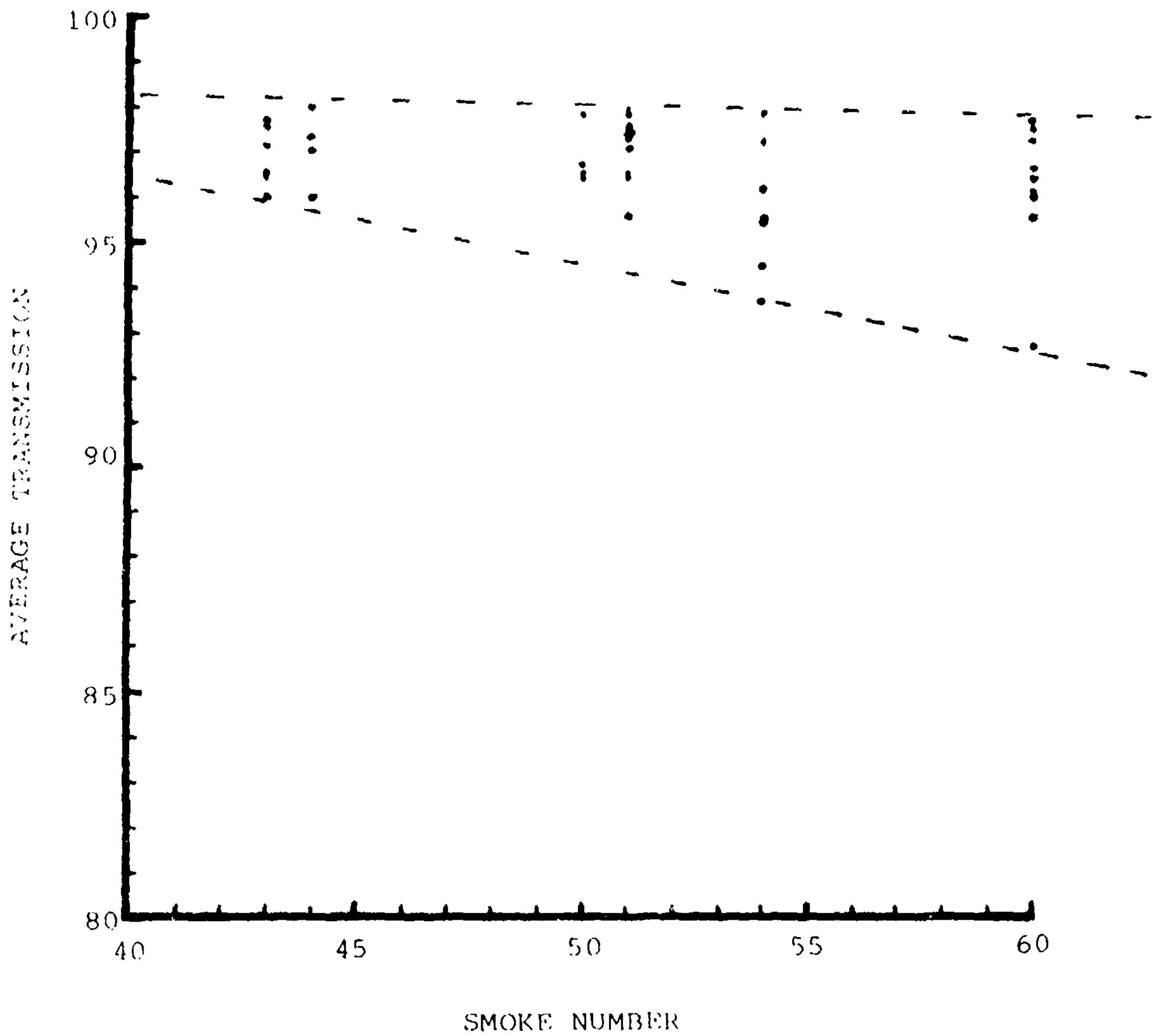


Figure 26. Average Transmission Versus Smoke Number

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SECTION V

5.0 SUMMARY

Major factors involved in the variability of the C-130 smoke plume transmission include the interaction of the output from multiple engines, changing plume viewing aspects, and variation in smoke dispersion from localized atmospheric conditions. During the flight tests the plume transmission was measured using calibrated photographic and visual observation methods. Inconsistency of plume shape and transmission from run to run, evident from the photographic records, made it very difficult to correlate transmission data to the engine Smoke Number setting and visual opacity readings.

The flight test summary in Table 5 describes the results of the test effort. The photographic data previously reported as transmission has been converted to "opacity" (100-percent transmission) so that the data could be tabulated in the form reported by USAF OEHL observers. The tabulated photographic data describe the average of the darkest areas and overall average of the plume on each frame throughout a run. The corresponding inflight power settings, ground and flight fuel flow, and ground test Smoke Numbers are also indicated.

The opacity reading of the smoke, as measured by the two observers, were found to be significantly different. Observations made by one observer showed a majority of the opacity readings between 10 and 30 (70 to 90 percent transmission) while readings by the second observer were between 0 and 10 (90 to 100 percent transmission). Some of these differences probably resulted from the variable test conditions involving a nonstationary C-130 aircraft and nonuniform sky backgrounds. As reported in USAF OEHL Report No. 80-27, both observers are certified by the Texas Air Control Board to conduct visual opacity determinations of stationary sources. The proper methods for accurate observation would have required the observer's lines-of-vision to be perpendicular to the plume direction, with several readings at the point of greatest opacity being made over a 6-minute period. Given the inconsistency of the observer readings, little correlation to the photographic measurements should be expected.

TABLE 5. INFLIGHT SUMMARY

Run	Fuel	OPACITY AVERAGE			Setting	Smoke #	Fuel Flow[1] (lb/hr)
		Vlaske	Stevens	Photographic (Darkest/Overall)			
2	JP-4	17.1	8.0	---	T/O & Climb	51	2125 (1700)
3	JP-4	21.4	11.7	---	Approach & Land	43	1000 (875)
4	JP-4	16.0	6.0	5.0	T/O & Climb	51	1020 (1700)
5	JP-4	15.8	6.0	7.7/3.3	Flt. Idle	44	710 (800)
6	JP-4	15.4	8.0	5.4/3.3	Approach	43	1075 (875)
7	JP-4	16.5	7.0	5.0/4.1	Cruise	50	1500 (1350)
8	JP-4	15.5	7.0	5.3/2.8	Climb	51	2000 (1700)
9	JP-4	18.8	5.0	4.6/3.0	T/O	51	2200 (1700)
11	JP-4	8.0	1.0	3.3/2.8	Flt. Idle	44	500 (800)
12	JP-4	9.5	3.3	4.2/3.05	Approach	43	1100 (875)
13	JP-4	12.5	5.0	3.0/2.15	Cruise	50	1500 (1350)
14	JP-4	11.0	4.2	4.75/2.9	Climb	51	2000 (1700)
15	JP-4	13.3	5.0	4.0/2.7	T/O	51	2100 (1700)
16	JP-5	9.4	4.0	3.4/2.4	Flt. Idle	53	600
18	JP-5	16.5	7.0	7.6/4.1	Approach	54	1100 (900)
20	JP-5	18.5	7.0	5.15/3.2	Cruise	60	1600 (1400)
21	JP-5	18.9	6.0	6.1/3.5	Climb	60	2000 (1800)
22	JP-5	16.4	5.0	5.4/3.25	T/O	61	2130 (1500)
23	JP-5	20.8	8.3	11.4/6.25	Approach & Land	54	600 (900)
24	JP-5	14.2	10.0	11.3/6.2	T/O & Climb	60	2000 (1800)
25	JP-5/JP-4	15.3/11.7	8.0	8.4/4.6/5.2	Approach & Land	54/43	1000 (900)
26	JP-5/JP-4	13.3/11.1	5.7	4.9/3.6/6.0	T/O & Climb	60/51	2100 (1800)
27	JP-5/JP-4	11.2[2]	4.2	6.2/3.8	T/O	55	2100 (1800)
28	JP-5/JP-4	10.0[2]	10.0	3.5/2.6	T/O	55	2100 (1800)

[1]Values in parentheses are from ground run-up

[2]Opacity readings on one engine, but field notes do not specify if engine was using JP-4 or JP-5.

Comparison of the photographic data to the engine Smoke Number, as measured from ground runup tests, provided an indication that the visible/invisible threshold (98 percent average Transmission = Opacity of 2) ranges between 33 and 48 for the C-130 aircraft. The threshold is based upon axial viewing of the plume, however, the variable interaction of the individual exhaust from the multiple engines made it impossible to identify a specific threshold. The threshold is close to a Smoke Number of 48 for cases where the viewing aspect allows the smoke from each engine to be viewed individually, i.e., little interaction among individual exhaust plumes. The threshold decreases as the apparent plume involves interaction among the smoke from all four engines, approaching a Smoke Number of 33.

The test program demonstrated the value of calibrated photographic methods for the measurement of smoke plume transmission and for documenting the two-dimensional nature of a visually observed smoke plume. Future effort should continue development of the measurement technique and define algorithms to reduce the measured transmission data to a single number (or parameter) that correlates with Smoke Number and visual opacity.

Future test programs should utilize co-located observers (several) and measurement cameras to reduce the number of variables during the test. The test plan/schedule should allow flexibility to obtain uniform, clear sky conditions since the photographic measurement technique is more accurate under these conditions.

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APPENDIX A

KODAK DATA RELEASE P-255

KODAK TECHNICAL PAN FILM

(ESTAR-AH BASE) EK2415

This document is included in this report to provide further information about the film selected for use in recording the smoke plume transmission data.

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TENTATIVE DATA

data release

P-255

KODAK TECHNICAL PAN FILM (ESTAR-AH BASE) ~~SO-115~~ EK2415

DESCRIPTION

KODAK Technical Pan Film (ESTAR-AH Base) SO-115 is a black-and-white negative film with extended red panchromatic sensitivity. It has extremely fine grain and extremely high resolving power. This film replaces two films used in a wide range of scientific and technical applications—KODAK Solar Flare Patrol Film (ESTAR-AH Base) SO-392 and KODAK Photomicrography Monochrome Film (ESTAR-AH Base) SO-410. SO-115 Film provides several advantages over the SO-392 and SO-410 Films. These include higher green sensitivity, higher resolving power and modulation transfer function (MTF), and better handling in sheet formats.

The SO-115 emulsion accommodates flexible processing to a wide range of contrasts. Gammas from 1 to 4 are achievable with conventional developers. KODAK Technical Pan Film can be processed to higher contrast and density than KODAK High Contrast Copy Film 5069. This contrast control is of special benefit, for example, in photomicrography of low-contrast specimens.

The dyed-gel backing layer suppresses curl as well as halation. The ESTAR-AH Base (with a 0.1 base density) permits handling of magazine-loaded film in subdued light.

APPLICATIONS

This film provides contrast enhancement of photomicrography specimens which are colorless, faintly stained, or intended for phase contrast or Nomarski illumination (such as chromosomal or karyotyping studies). It requires reduced exposure times with green filtration in photomicrography compared with SO-410 Film.

In solar recording it replaces KODAK Solar Flare Patrol Film SO-392 for solar disk recording and provides information on solar phenomena occurring throughout the green wavelengths as well as at the H-alpha line.

It is excellent for photographing the images reconstructed from holograms where the playback illuminant is a helium-neon laser (633 nm). It may also be used to record the output of light-emitting diodes (LEDs), which peak at 640 to 660nm, and plasma displays.

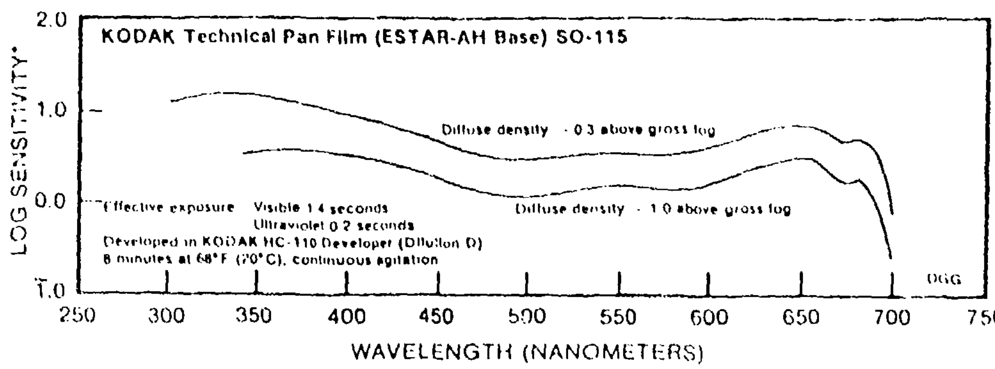
Because it can provide very high contrast and maximum density when processed in selected conventional developers, this film is very useful for making black-and-white slides.

This film will find other applications where speed/grain ratio is important, where both high resolution and camera speed are important, or where a wide range of contrast control is necessary.

SPECTRAL SENSITIVITY

The spectral sensitivity of SO-115 Film reflects an extensive effort to provide reasonably uniform sensitivity at all visible wavelengths while retaining the exceptional red sensitivity (and other valuable properties) of SO-392 and SO-410 Films. To achieve a closer approximation to flat response, some users may wish to make exposures through a color compensating filter which selectively attenuates red and blue-UV radiation, e.g., KODAK Color Compensating Filter CC40C or CC50C (Cyan). The effect of using such a filter will be to yield reasonably flat response out to 655nm. Note, in comparison, that films having conventional panchromatic sensitivity are designed to provide flat response only out to 625 nm. Thus, even with a CC50C Filter in place, SO-115 Film will record red portions of a scene relatively more efficiently than materials such as KODAK PANATOMIC-X Film or KODAK PLUS-X Pan Film.

SPECTRAL SENSITIVITY



*Sensitivity equals reciprocal of exposure (ergs/cm²) required to produce densities specified

IMAGE STRUCTURE CHARACTERISTICS

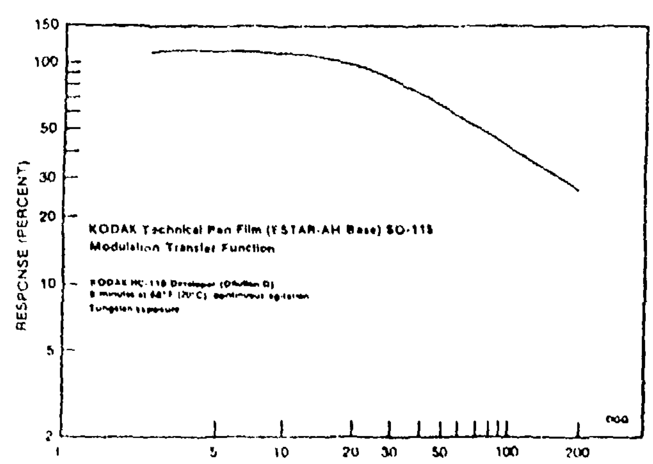
All data given in this section is based on development in KODAK HC-110 Developer (Dilution D) at 68°F (20°C) for 8 minutes.

Resolving Power

Test-Object Contrast	Resolving Power (lines/mm)
1000:1	320
1.6:1	125

Modulation Transfer Function

These photographic modulation transfer values were determined using a method similar to that of a proposed ANSI Standard. The film was exposed with the specified illuminant to spatially varying sinusoidal test patterns having an aerial image modulation of a nominal 35 percent at the image plane, with processing as indicated. In most cases, these photographic modulation transfer values are influenced by development adjacency effects, and are not equivalent to the true optical modulation transfer curve of the emulsion layer in the particular photographic product.



Diffuse RMS Granularity

8 (extremely fine)

This value represents 1000 times the standard deviation in density produced by the granular structure of the material when a uniformly exposed and developed sample is scanned with a microdensitometer calibrated to read American National Standard *diffuse* visual density and having a 48 μm circular aperture. Granularity is an objective measurement of the spatial variation of sample density that generally correlates with graininess, which is the subjective effect of the image nonuniformity upon an observer.

Broadly speaking, granularity measurements with the 48 μm aperture will indicate the magnitude of the graininess sensation produced by viewing the *diffusely* illuminated sample with 12X monocular magnification. If the viewing conditions are changed from the specified 12X condition, the published rms values may no longer correctly indicate the relative sensations of graininess produced by various samples.

EXPOSURE, FILM SPEED AND CONTRAST

The following are suggested starting exposure conditions. Since there are a wide range of unique exposure situations in which this film may be used, we give recommendations only for the most common applications. Note that the exposure index is closely related to the processing conditions and the resulting contrast. Compare the tables presented with the characteristic curves in choosing the appropriate contrast and exposure index. Values given are for use with meters marked for ASA speeds or exposure indexes and are suggested starting points for trial exposures. Bracketing exposures by full-stop intervals will usually be required for initial tests.

Exposure Indexes for Photomicrography

The following exposure index (EI) values are intended as starting points for trial exposures to give satisfactory results with photomicrography equipment having through-the-lens meters. The indexes are based on the formula EI = 10/E, where E is the 1-second exposure in meter-candle-seconds required to produce a density of 0.6 above minimum density with the indicated development.

Tungsten Exposure Index

In KODAK Developer*	Development Time (minutes) at 68°F (20°C)	Contrast Index	Gamma	Exposure Index
D-19	4	2.9 maximum	4.0	100
HC-110 (Dilution D)	8	1.7	1.9	100
HC-110 (Dilution F)	8	1.4	1.8	50

Filter Factors for Photomicrography

The following values are based on 1-second tungsten exposures with development for 8 minutes at 68°F (20°C) in KODAK HC-110 Developer, Dilution D:

KODAK WRATTEN Filter	Filter Factor†
No. 11 (yellowish-green)	5
No. 12 (deep yellow)	1.25
No. 13 (dark yellowish-green)	6.4
No. 25 (red tricolor)	2
No. 47 (blue tricolor)	25
No. 58 (green tricolor)	12.5

Pictorial (Full-Range) Photography

Conventional developers used with this film will generally produce contrast too high for normal pictorial photography. In addition, the extended red sensitivity of this material will generally cause poor rendition of skin tones when photographing people. However, it may still be desirable in specialized applications to take advantage of the extremely fine grain and high resolving power of SO-115 Film when photographing scenes or subjects having a wide range of brightnesses. In such cases, the user may find it rewarding to experiment with specialized low-contrast developers. Most such developers are relatively unstable and must be prepared shortly before use. An example is POTA Developer‡. Suggested meter setting for trial exposures on film to be processed with this developer in a small tank for 15 minutes at 68°F (20°C) is

EI 25 (Daylight)

This exposure index is based on the formula EI = 0.8/E, where E is the exposure (at 1/25-second) in meter-candle-seconds required to produce a density of 0.1 above minimum density with the indicated development.

Speed and Contrast with Machine Processing

Processing in a KODAK VERSAMAT Film Processor, Model 11, will yield these speed and contrast results:

KODAK Developer	Developer Temperature	Machine Speed (ft/min)	Developer Racks	Contrast Index	Gamma	Exposure Index
VERSAMAT 641	85°F (29.5°C)	7.5	1	2.25	2.8	160 (Daylight)§
VERSAFLO	80°F (26.5°C)	10.0	2	1.5	1.8	80 (Tungsten)

* Processed in a small tank with agitation at 30-second intervals

† When using through-the-lens exposure meters, read the exposure without the filter in place. Then use the filter factor to compute the correct exposure. Depending upon the actual response of the meter, reading exposures through the filter may give erroneous results.

‡ See "Wide Latitude Photography" by Marilyn Levy in *Photographic Science and Engineering*, Volume 11, No. 1 January-February, 1967, pages 46-53. For additional information on this topic, write to Scientific and Technical Photography, Dept. 757, Eastman Kodak Company, Rochester, N.Y. 14650

§ Based on 1/25-second exposure time

RECIPROCITY FAILURE

When tungsten exposures are made at times appreciably more or less than 1 second, changes in speed or contrast may be noted. The following corrections will be necessary:

Changes in Speed and Contrast Due to Reciprocity Effect

Exposure Time (seconds)

	1000	100	10	1	1/10	1/100	1/1000	1/10000
Contrast Index Change	-10%	None	None	None	-5%	-5%	-10%	-10%
Speed Change	-70%	-50%	-20%	None	+20%	+20%	None	None
Exposure Change Required (camera stops)	+1 2/3	+1	+1/3	None	-1/3	-1/3	None	None
Adjusted Exposure Index	32	50	80	100	125	125	100	100

Based on development in KODAK HC-110 Developer (Dilution D) for 8 minutes at 68°F (20°C) in a sensitometric processing machine with agitation at 8-second intervals to give a contrast index of 1.9

PROCESSING

Small Tank Processing

For processing in small tanks with spiral reels, agitation at 30-second intervals, use the following sequence:

Develop to the desired contrast index based on information in the exposure section and on the characteristic curves. The contrast index obtained depends primarily upon the developer, temperature, dilution, and development time chosen. It is affected to a lesser extent by exposure time (see reciprocity failure), specific processing techniques, and normal product variability. Therefore, the times given should be considered as starting points only.

Rinse in KODAK Stop Bath SB-1a for 15 to 30 seconds at 65 to 70°F (18 to 21°C).

Fix as follows with frequent agitation at 65 to 70°F (18 to 21°C).

In KODAK Fixer or KODAK Fixing Bath F-5	2 to 4 minutes
In KODAK Rapid Fixer	1½ to 3 minutes

Wash in running water for 5 to 15 minutes at 65 to 70°F (18 to 21°C), depending upon reduction of residual hypo needed. For faster washing and less water consumption, rinse the fixed film in running water for 15 seconds to remove excess hypo. Bathe the film in KODAK Hypo Clearing Agent for 30 seconds with agitation. Then wash the film for 1 minute in running water at 65 to 70°F (18 to (21°C), allowing at least one change of water during this time.

Dry the film in a dust-free place. Heated forced-air drying at 120 to 140°F (49 to 60°C) may be used to reduce drying time.

Machine Processing

Using the KODAK VERSAMAT Film Processor, Model 11, and the listed chemicals, follow one of the processing sequences described below. For both processing sequences, fixing and drying are adequate at the recommended machine speeds. The user should run tests to determine that washing quality is adequate for his needs.

KODAK VERSAMAT 641 Developer Replenisher
KODAK VERSAMAT 641 Developer Starter
KODAK VERSAMAT 641 Fixer and Replenisher

Processing Sequence

Step	No. of Racks	Path Length	Temperature
Develop	1	4 ft (1.2 m)	85 ± ¼°F (29 5 ± 0 3°C)
Fix	3	12 ft (3 8 m)	85°F (29 5°C) *nominal*
Wash	2	8 ft (2 4 m)	75 to 80°F (24 to 26 5°C)
Dry	—	8 ft (2 4 m)	135 to 140°F (57 to 60°C)

To produce a gamma of about 2 8, start with a machine speed of 7.5 feet per minute (2.3 m/min).

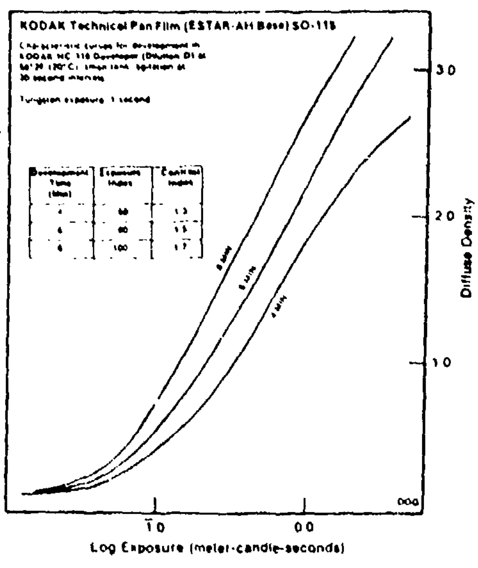
KODAK VERSAFLO Developer Replenisher
KODAK VERSAFLO Developer Starter
KODAK Rapid Fixer

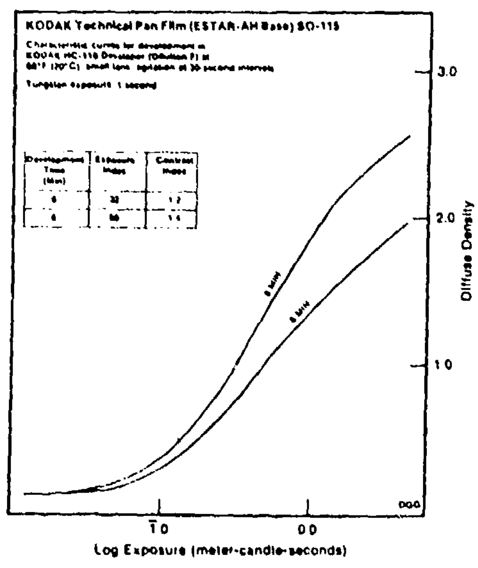
Processing Sequence

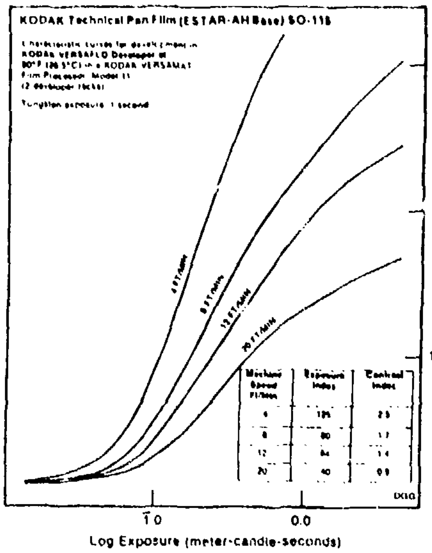
Step	No. of Racks	Path Length	Temperature
Develop	2	8 ft (2 4 m)	80 ± ¼°F (26.5 ± 0.3°C)
Fix	3	12 ft (3.8 m)	80°F (26 5°C) *nominal*
Wash	2	8 ft (2 4 m)	70 to 75°F (21 to 24°C)
Dry	—	8 ft (2.4 m)	135 to 140°F (57 to 60°C)

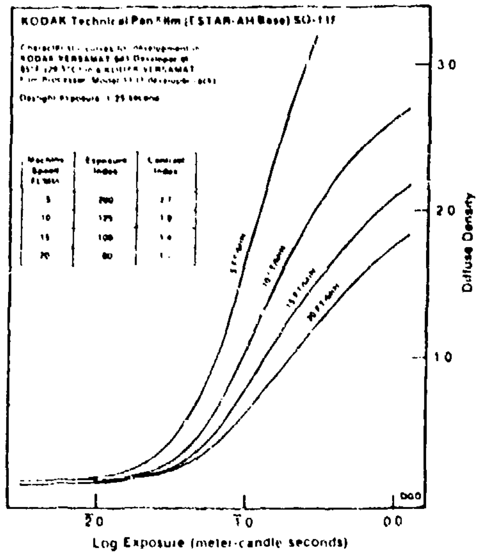
To produce a contrast index of about 1 5, start with a machine speed of 10 feet per minute (3m/min). Washing is not sufficient to provide archival quality but should be adequate for many scientific recording applications. The 4 x 5-inch sheet film may cause transport difficulties when processing with VERSAFLO Developer.

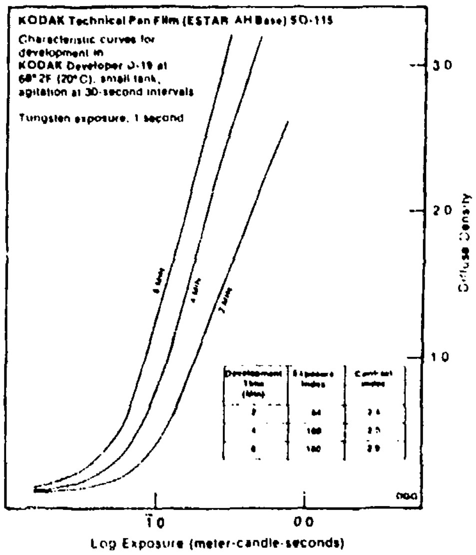
CHARACTERISTIC CURVES






KODAK Technical Pan Film (ESTAR-AH Base) SO-115
Tungsten exposure, 1 second
3.0
2.0
1.0
Diffuse Density
1.0
0.0
Log Exposure (meter-candle-seconds)


KODAK Technical Pan Film (ESTAR-AH Base) SO-115
3.0
2.0
1.0
Diffuse Density
2.0
1.0
0.0
Log Exposure (meter-candle-seconds)


KODAK Technical Pan Film (ESTAR AH Base) SO-115
Characteristic curves for
development in
KODAK Developer D-19 at
68° 2F (20° C), small tank,
agitation at 30-second intervals
Tungsten exposure, 1 second
3.0
2.0
1.0
Diffuse Density
1.0
0.0
Log Exposure (meter-candle-seconds)

HANDLING AND STORAGE

Keep unopened boxes of film at 70°F (21°C) or below. Allow cold film to reach room temperature before opening the package (2 hours if refrigerated, 3 hours if frozen). Load and unload the camera in subdued light, and rewind the film completely into the magazine before unloading the camera. For best results, process the film as soon as possible after exposure.

Total darkness is required when removing the film from the magazine and in processing. However, after development is half completed, a suitable safelight lamp with a 15-watt bulb and a KODAK Safelight Filter No. 3 (dark green), or equivalent safelight conditions, can be used for a few seconds if the safelight is kept at least 4 feet (1.2 meters) from the film.

FILM SIZES AND ORDERING INFORMATION

Three sizes are listed and are available in single units through dealers who serve the professional photographer. Because this film is a special-order product, your dealer may not have it in stock. He can order the film in the listed sizes for you. The 150-foot rolls are wound on small diameter cores so that the outside diameter of the rolls will be compatible with 35 mm bulk-film loaders. The 4 x 5-inch sheet film package contains two 25-sheet hermetically sealed envelopes.

Size & Specification	CAT. No.
135-36 magazine	129 7563
35 mm x 150 ft Sp 651 (Type AA core, KS perf)	129 9916
4 x 5-inch, 50 sheets per pkg	152 4594

Other sizes may be made available subject to minimum order quantities. Minimum order quantities for special-order sizes correspond generally to 750 square feet of film.

The sensitometric curves and data in this publication represent product tested under the conditions of exposure and processing specified. They are representative of production coatings and, therefore, do not apply directly to a particular box or roll of photographic material. They do not represent standards or specifications which must be met by Eastman Kodak Company. The Company reserves the right to change and improve product characteristics at any time.

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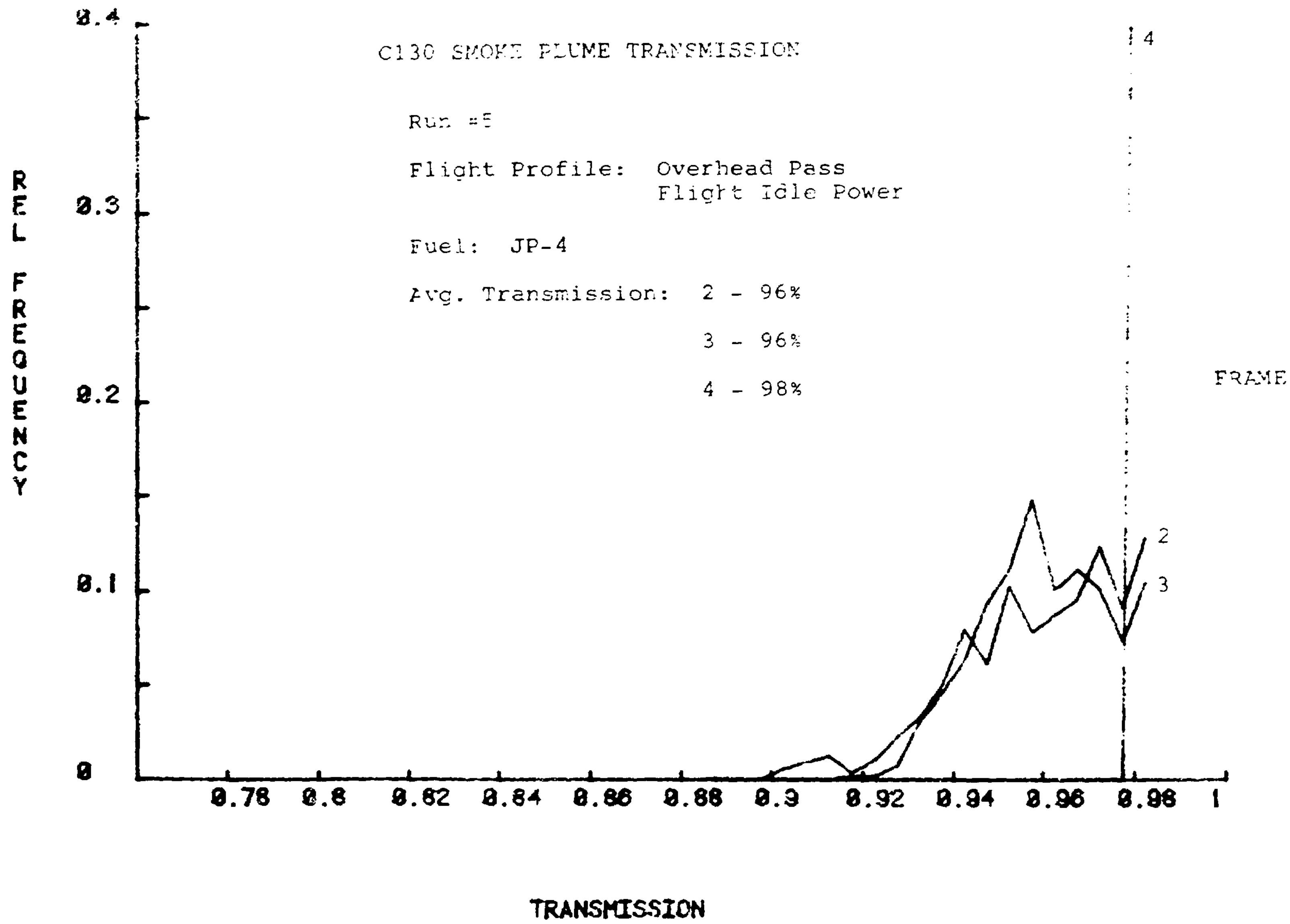
APPENDIX B

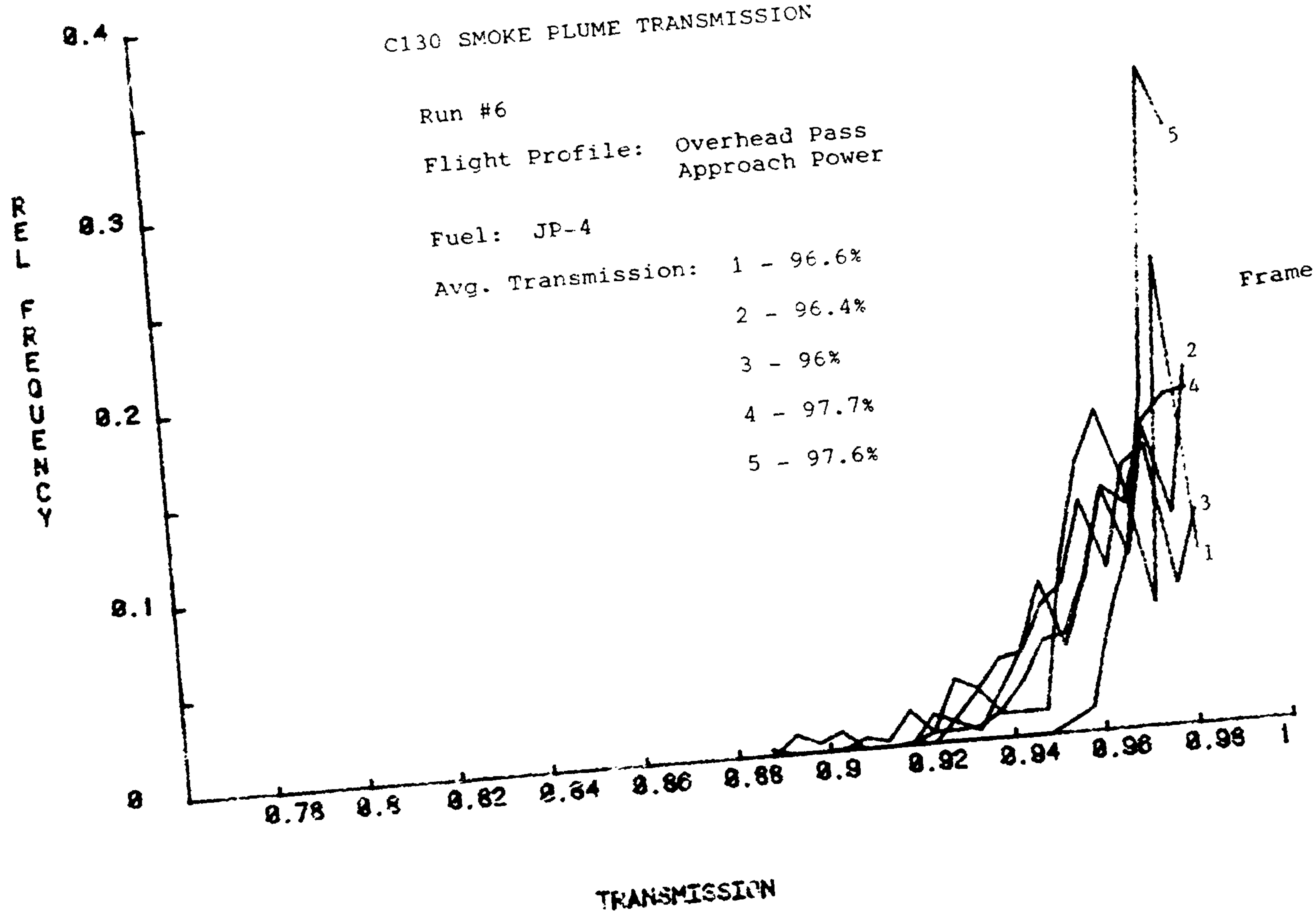
TRANSMISSION FREQUENCY

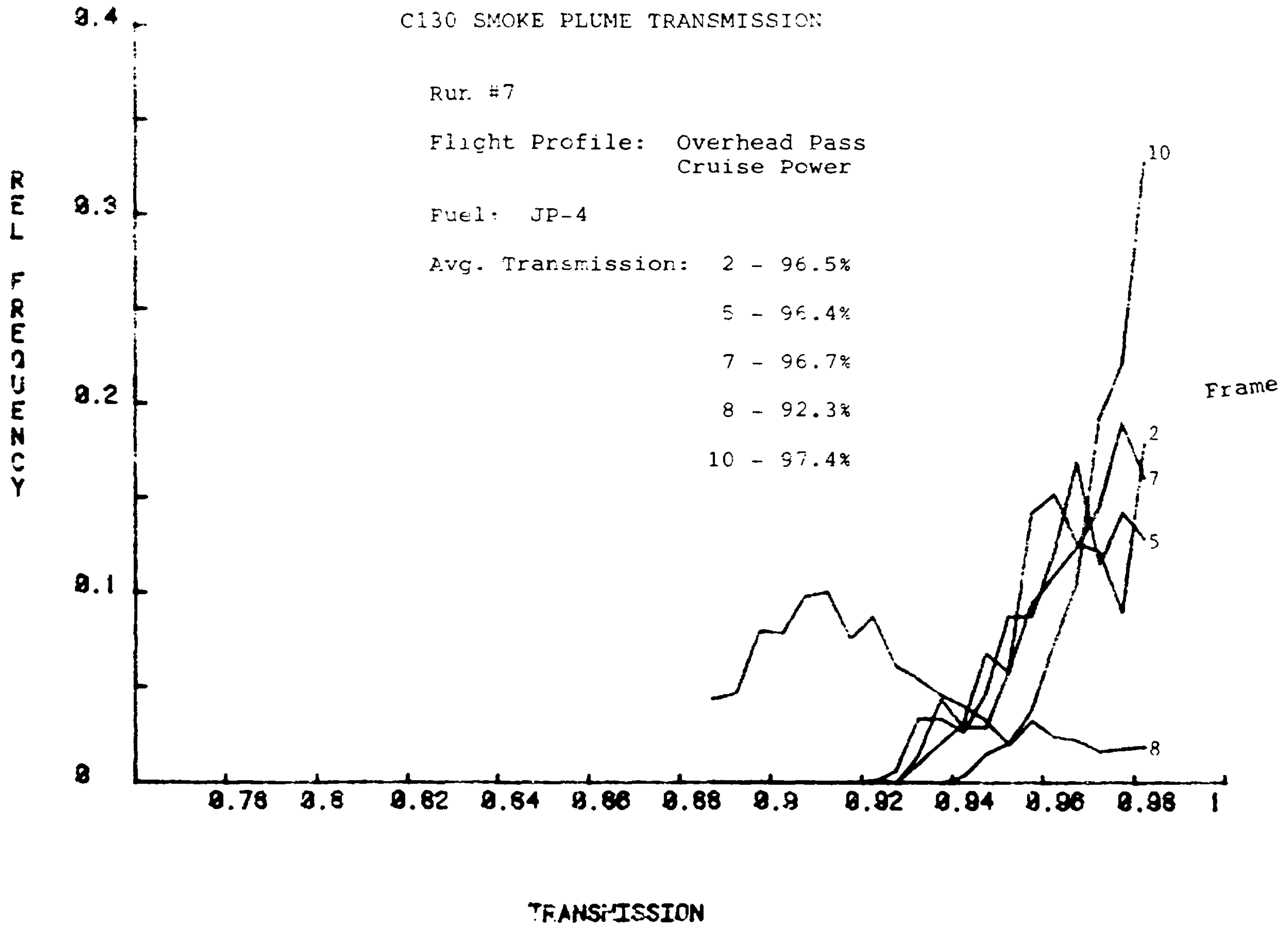
DISTRIBUTION DATA

RUNS 5 THROUGH 28

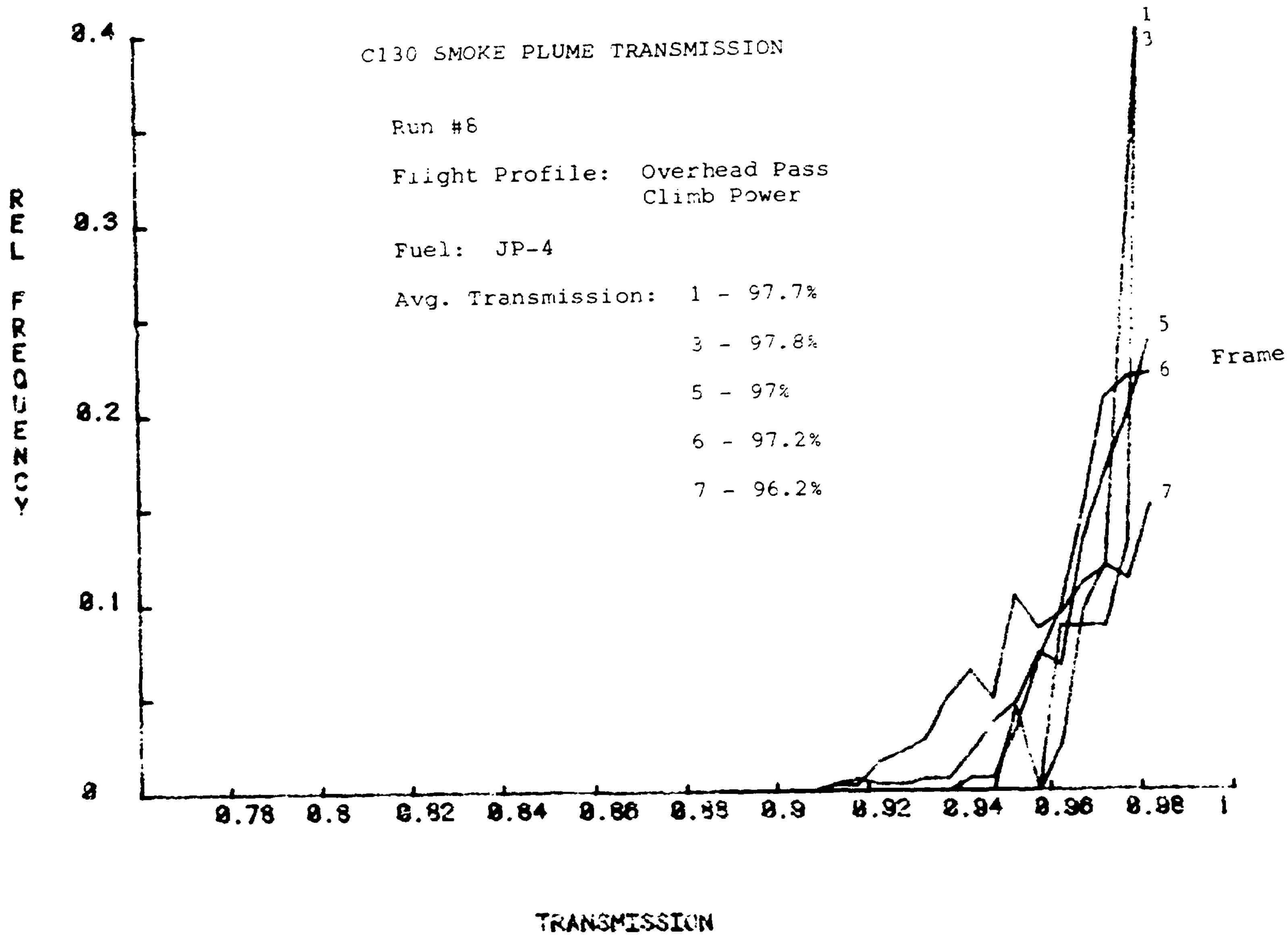


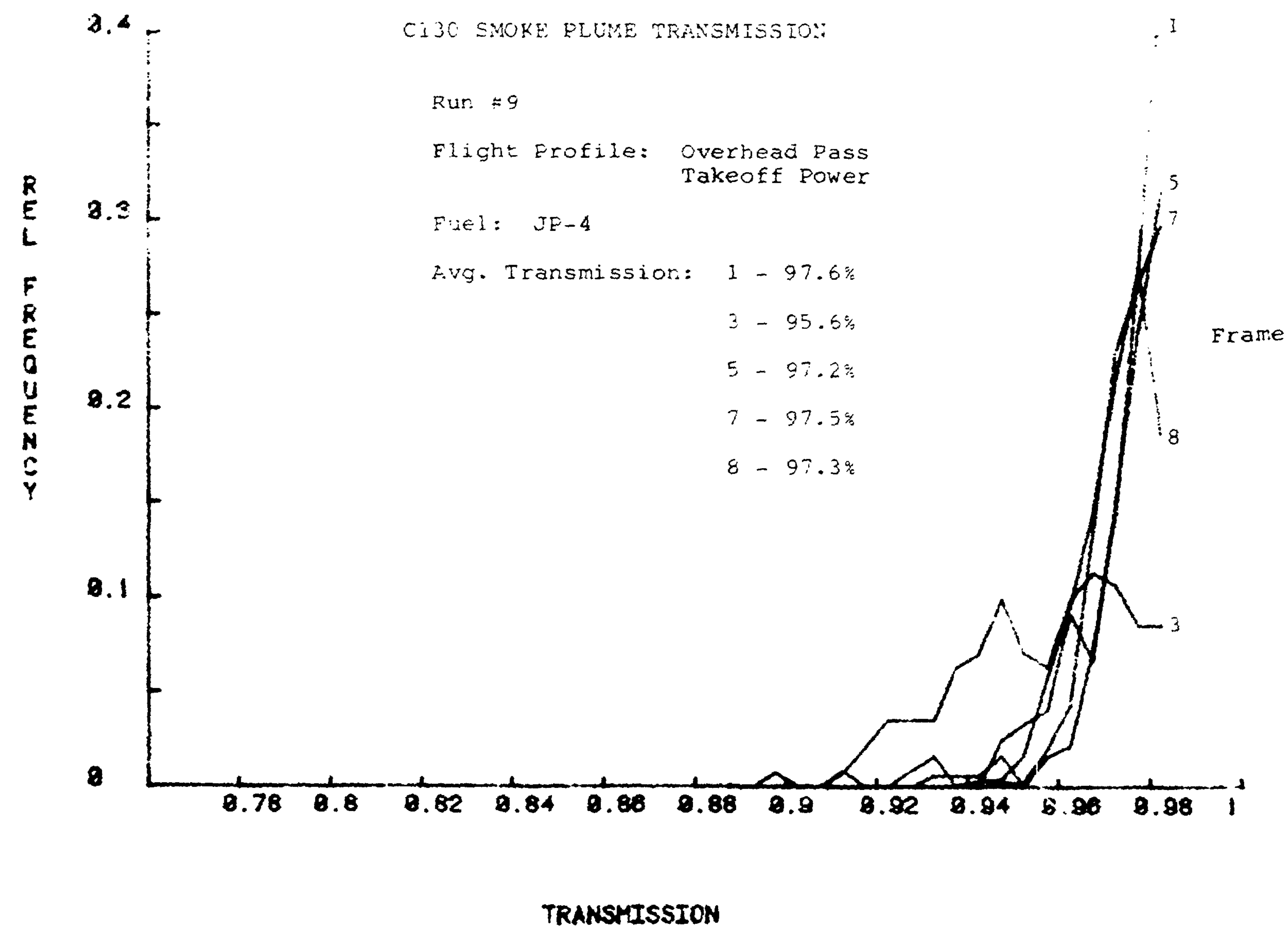
C130 SMOKE PLUME TRANSMISSION
Run #5
Flight Profile: Overhead Pass
Flight Idle Power
Fuel: JP-4
Avg. Transmission: 2 - 96%
3 - 96%
4 - 98%
FRAME
REL FREQUENCY
TRANSMISSION
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
2
3
4

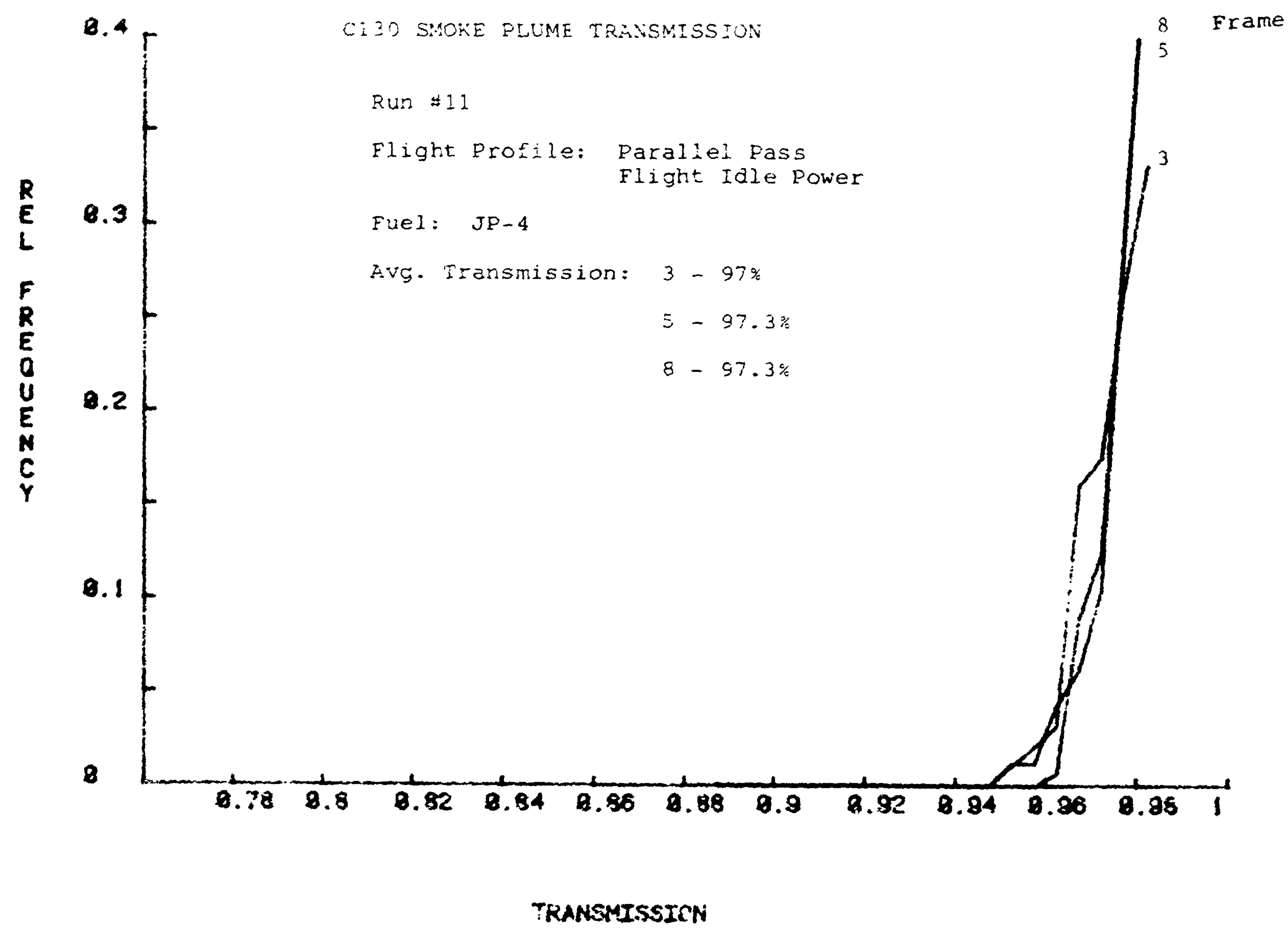

C130 SMOKE PLUME TRANSMISSION
Run #6
Flight Profile: Overhead Pass
Approach Power
Fuel: JP-4
Avg. Transmission: 1 - 96.6%
2 - 96.4%
3 - 96%
4 - 97.7%
5 - 97.6%
Frame
1
2
3
4
5
REL FREQUENCY
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION

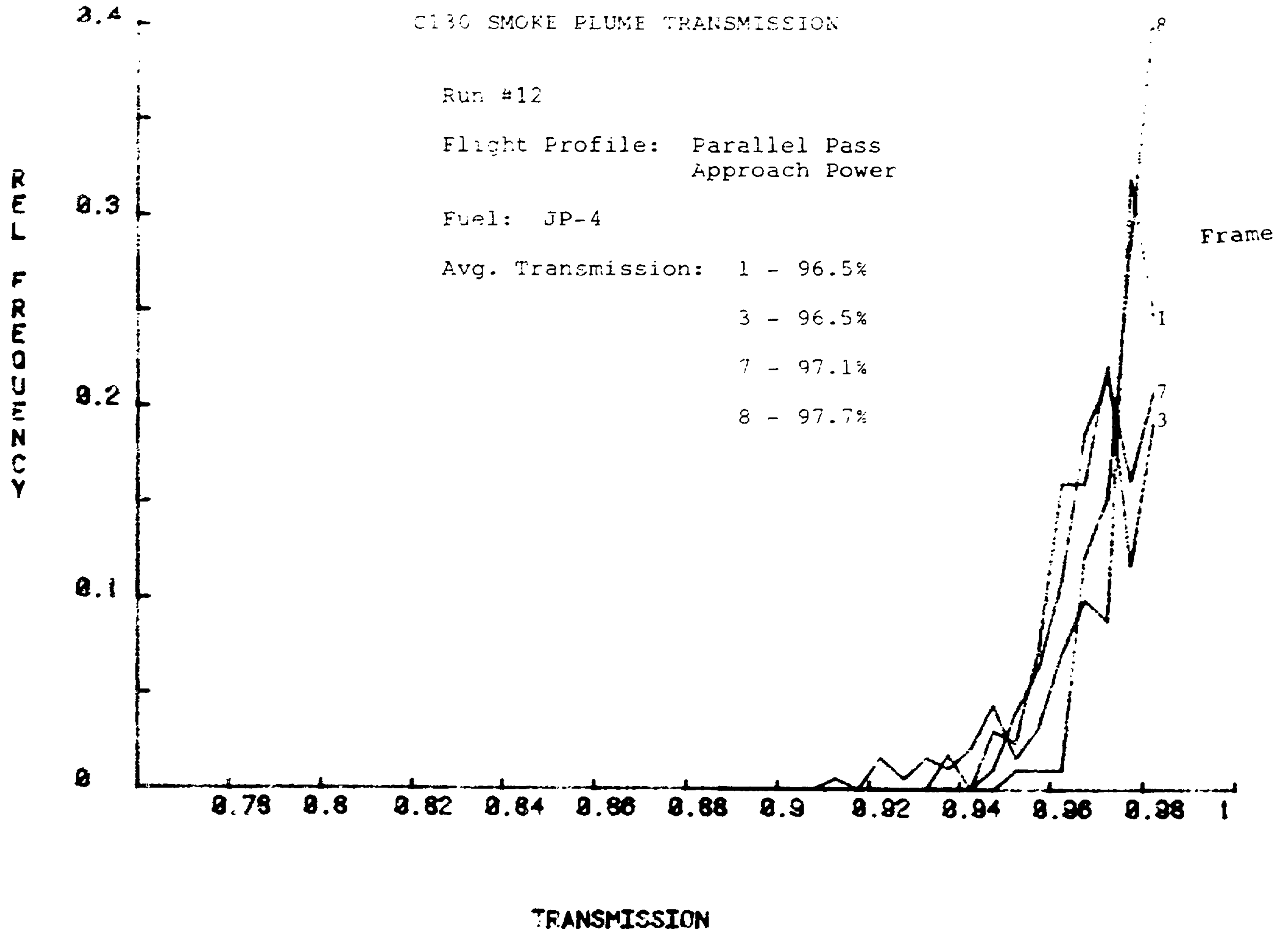


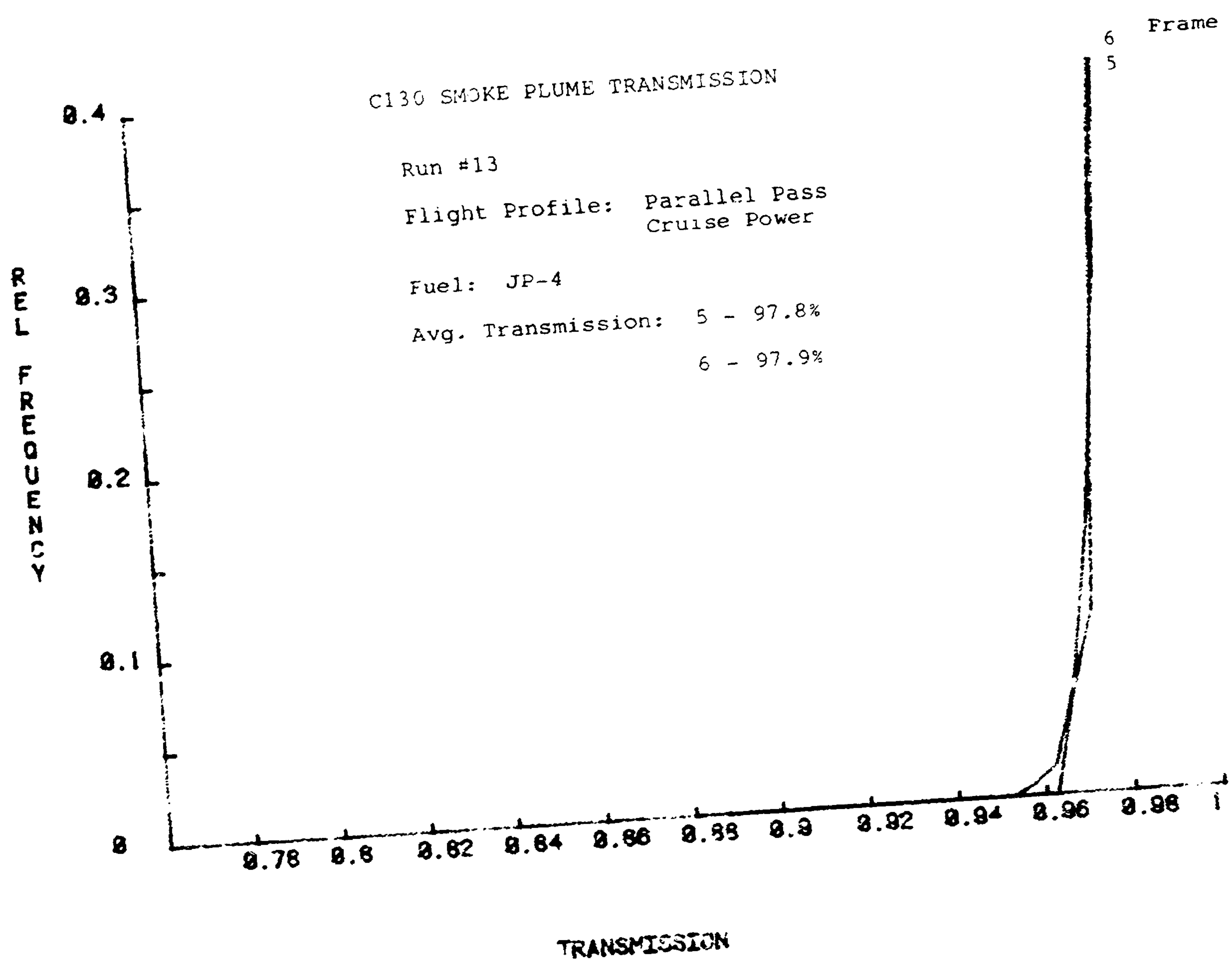
C130 SMOKE PLUME TRANSMISSION
Run #7
Flight Profile: Overhead Pass
Cruise Power
Fuel: JP-4
Avg. Transmission: 2 - 96.5%
5 - 96.4%
7 - 96.7%
8 - 92.3%
10 - 97.4%
Frame
10
2
7
5
8
REL FREQUENCY
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION

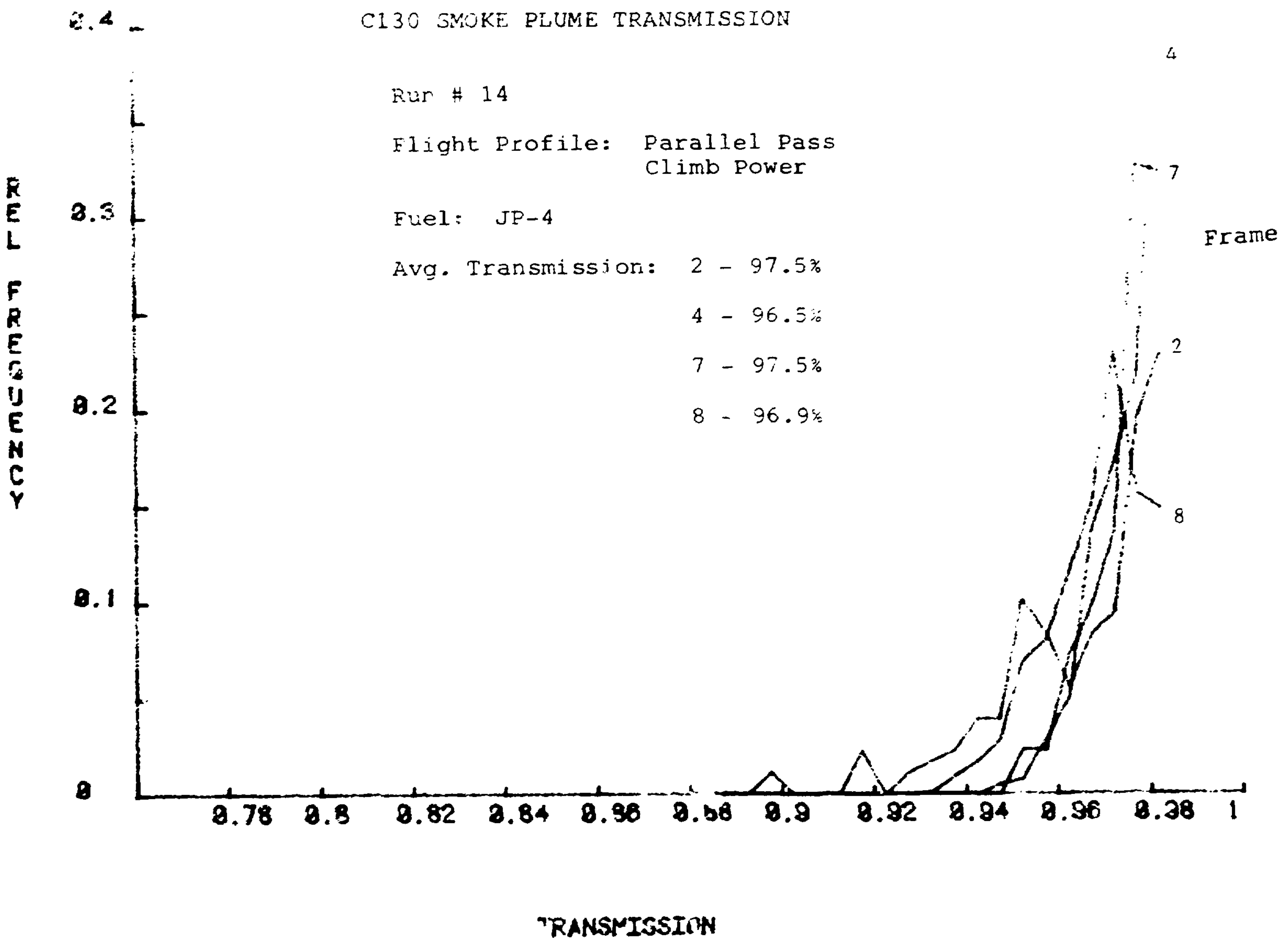

C130 SMOKE PLUME TRANSMISSION
Run #8
Flight Profile: Overhead Pass
Climb Power
Fuel: JP-4
Avg. Transmission: 1 - 97.7%
3 - 97.8%
5 - 97%
6 - 97.2%
7 - 96.2%
Frame
1
3
5
6
7
REL FREQUENCY
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION

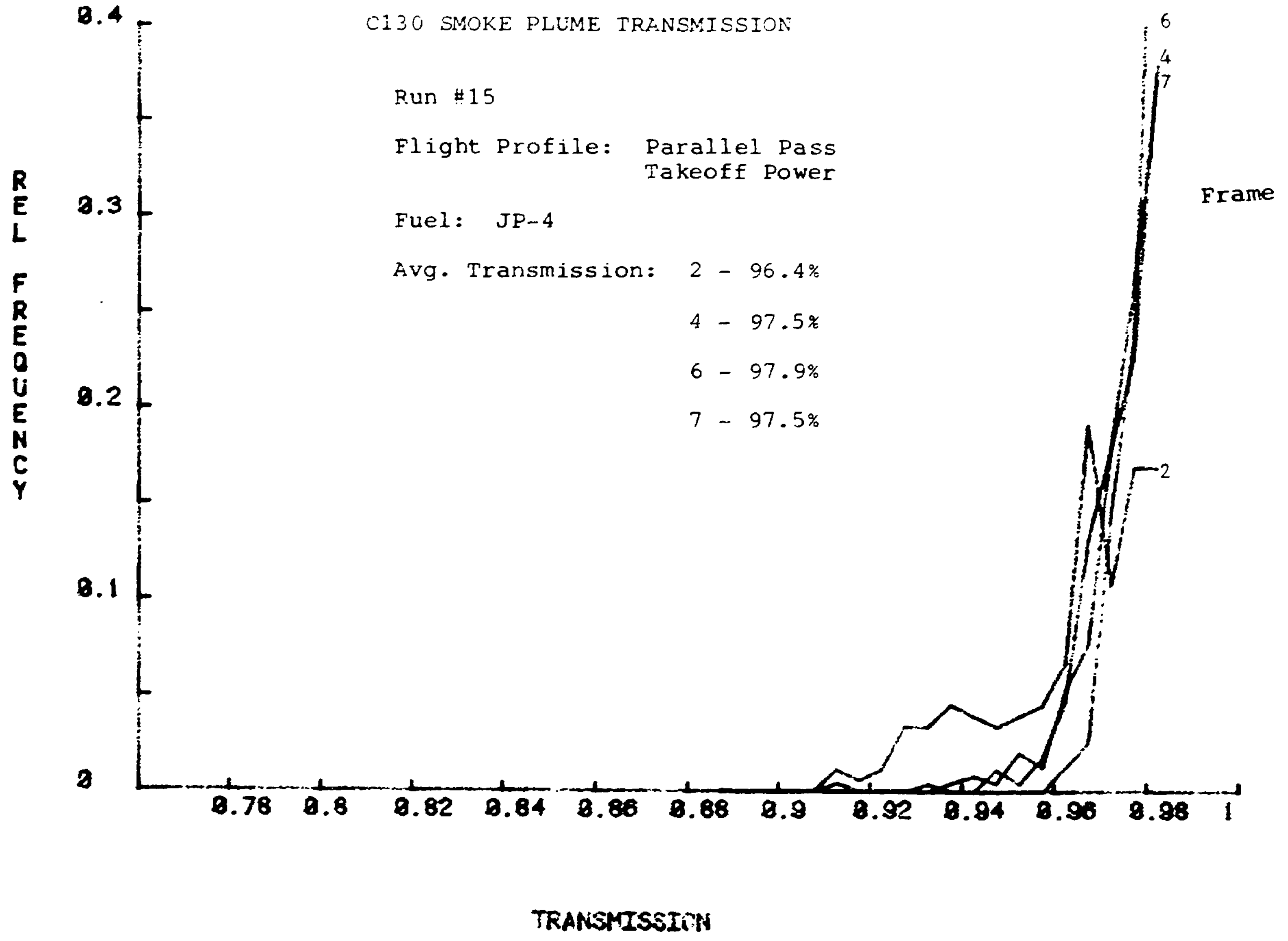

C130 SMOKE PLUME TRANSMISSION
Run #9
Flight Profile: Overhead Pass
Takeoff Power
Fuel: JP-4
Avg. Transmission: 1 - 97.6%
3 - 95.6%
5 - 97.2%
7 - 97.5%
8 - 97.3%
Frame
1
3
5
7
8
REL FREQUENCY
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION

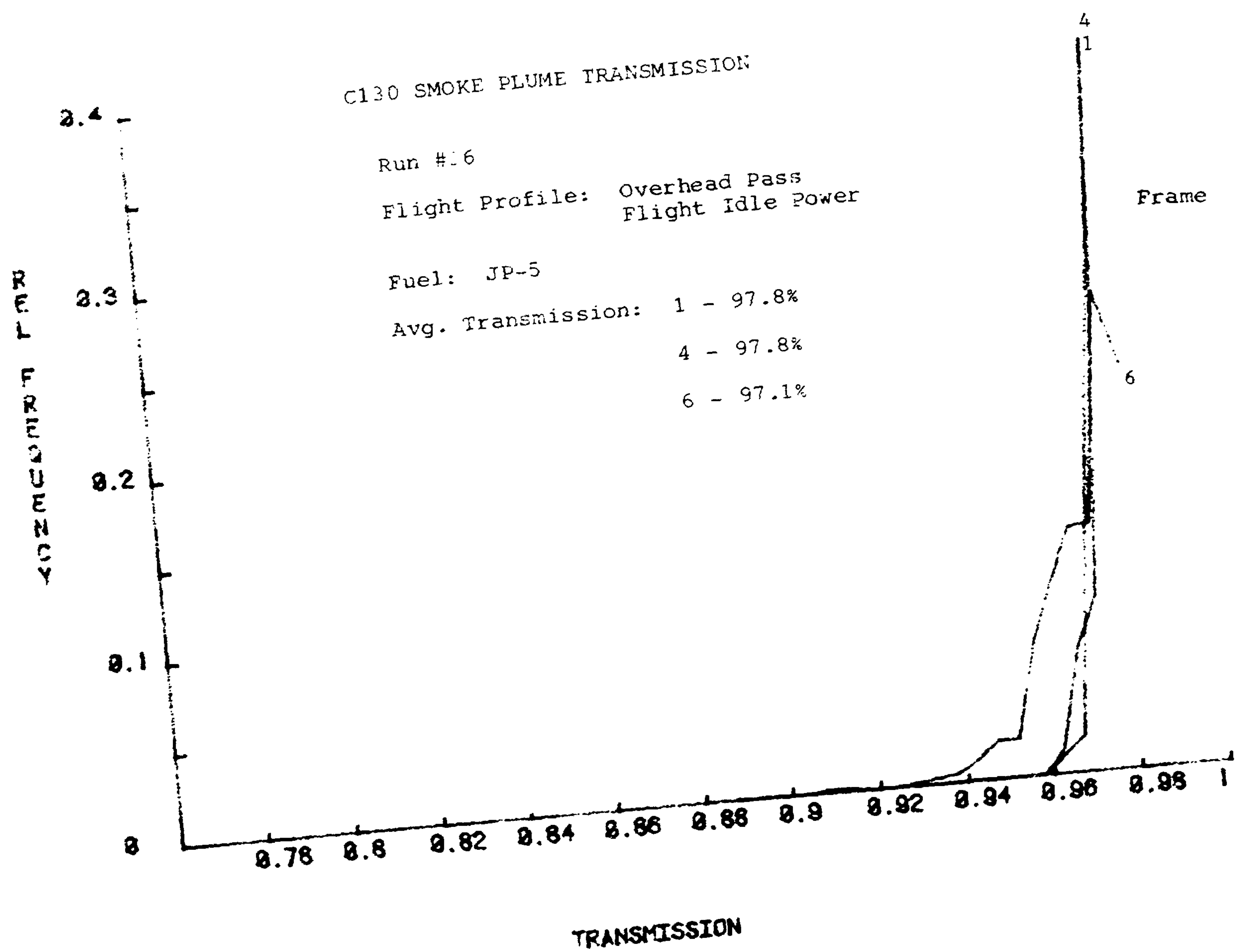

C130 SMOKE PLUME TRANSMISSION
Run #11
Flight Profile: Parallel Pass
Flight Idle Power
Fuel: JP-4
Avg. Transmission: 3 - 97%
5 - 97.3%
8 - 97.3%
Frame
8
5
3
REL FREQUENCY
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION

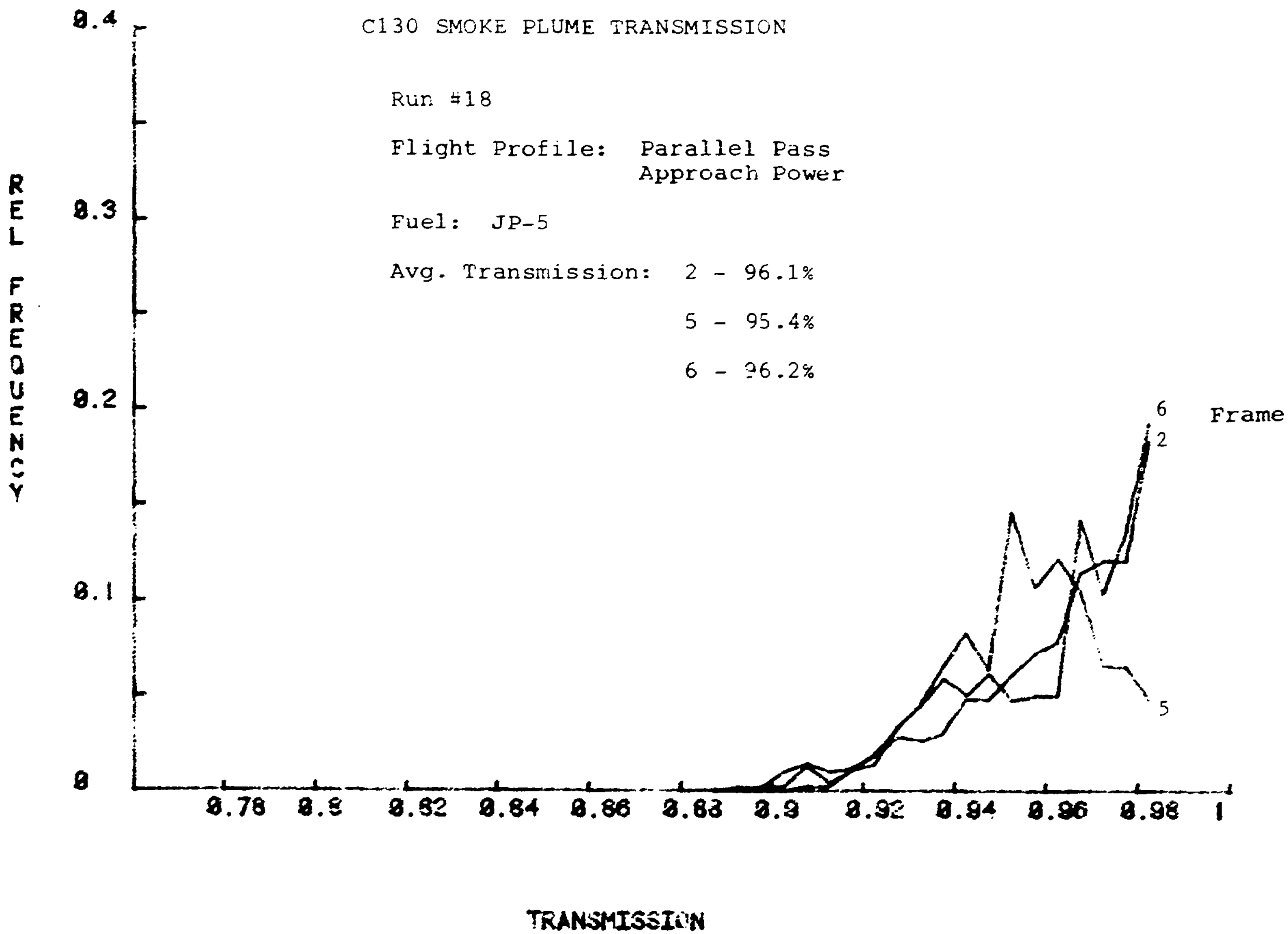

C130 SMOKE PLUME TRANSMISSION
Run #12
Flight Profile: Parallel Pass Approach Power
Fuel: JP-4
Avg. Transmission: 1 - 96.5%
3 - 96.5%
7 - 97.1%
8 - 97.7%
Frame
1
3
7
8
REL FREQUENCY
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION

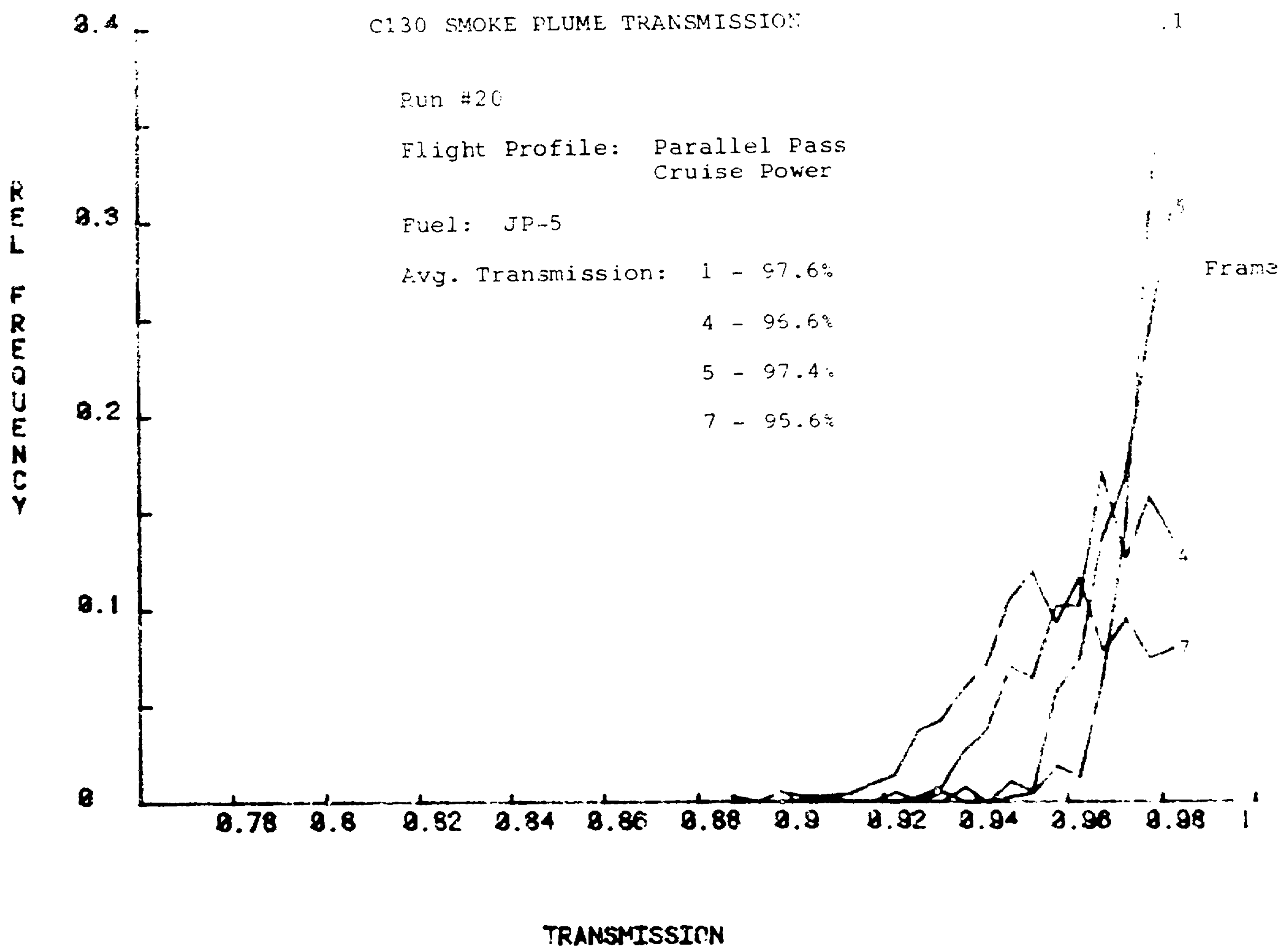

C130 SMOKE PLUME TRANSMISSION
Run #13
Flight Profile: Parallel Pass
Cruise Power
Fuel: JP-4
Avg. Transmission: 5 - 97.8%
6 - 97.9%
Frame
6
5
REL FREQUENCY
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION


C130 SMOKE PLUME TRANSMISSION
Rur # 14
Flight Profile: Parallel Pass
Climb Power
Fuel: JP-4
Avg. Transmission: 2 - 97.5%
4 - 96.5%
7 - 97.5%
8 - 96.9%
Frame
4
7
2
8
REL FREQUENCY
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
'RANSMISSION

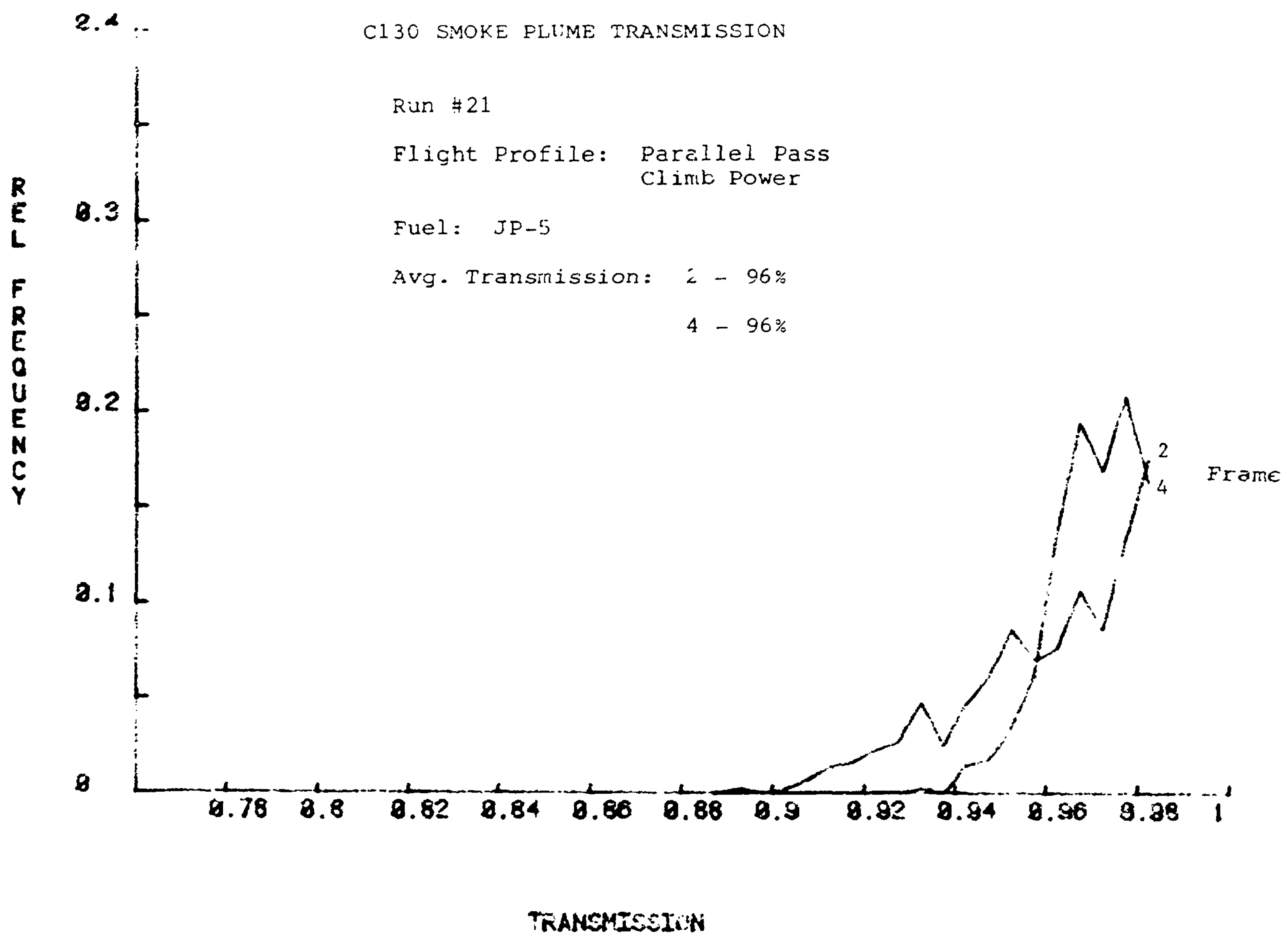

C130 SMOKE PLUME TRANSMISSION
Run #15
Flight Profile: Parallel Pass Takeoff Power
Fuel: JP-4
Avg. Transmission: 2 - 96.4%
4 - 97.5%
6 - 97.9%
7 - 97.5%
Frame
6
4
7
2
REL FREQUENCY
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION

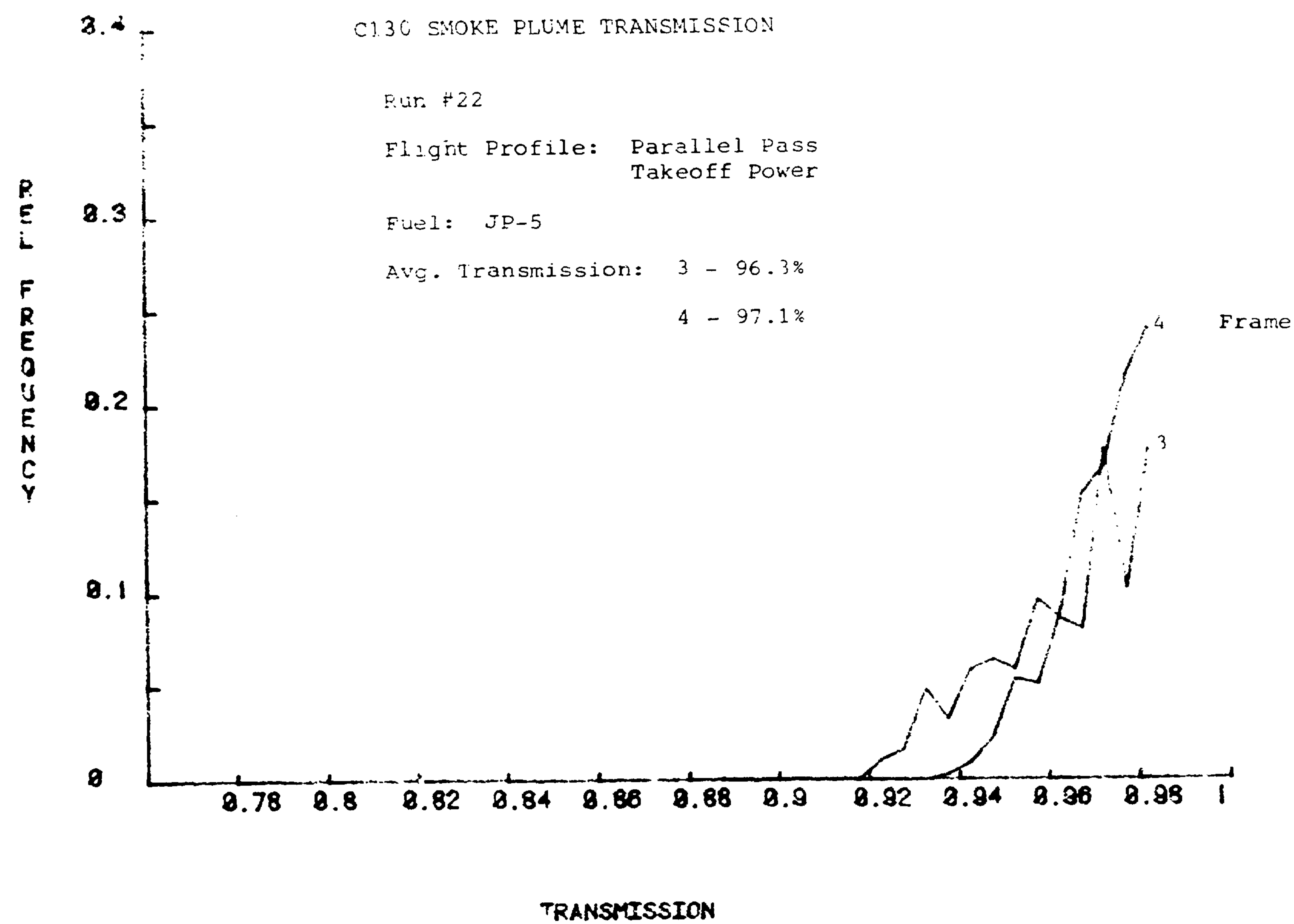

C130 SMOKE PLUME TRANSMISSION
Run #16
Flight Profile: Overhead Pass
Flight Idle Power
Fuel: JP-5
Avg. Transmission: 1 - 97.8%
4 - 97.8%
6 - 97.1%
Frame
4
1
6
REL FREQUENCY
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION

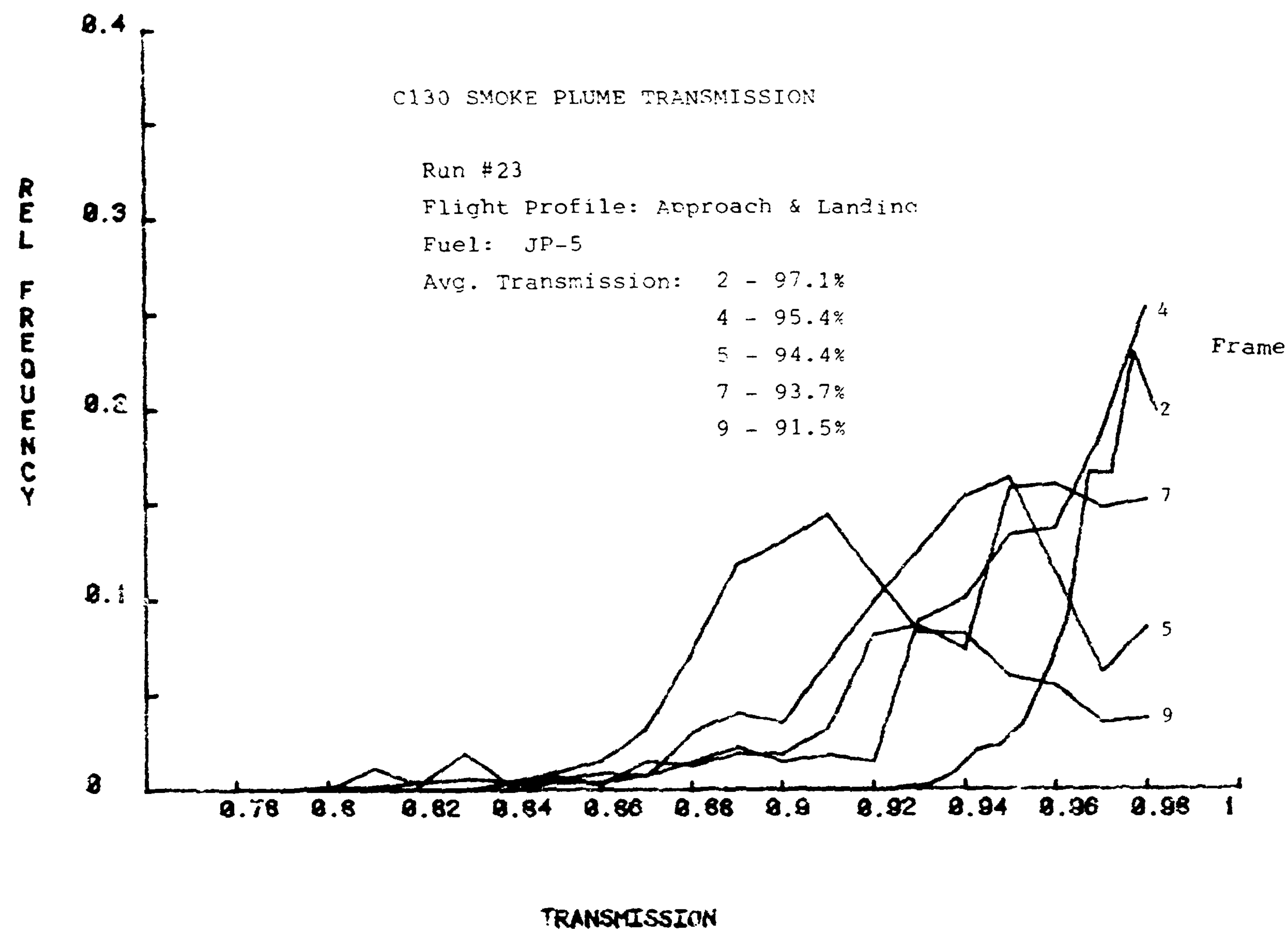

C130 SMOKE PLUME TRANSMISSION
Run #18
Flight Profile: Parallel Pass Approach Power
Fuel: JP-5
Avg. Transmission: 2 - 96.1%
5 - 95.4%
6 - 96.2%
Frame
6
2
5
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
REL FREQUENCY
TRANSMISSION

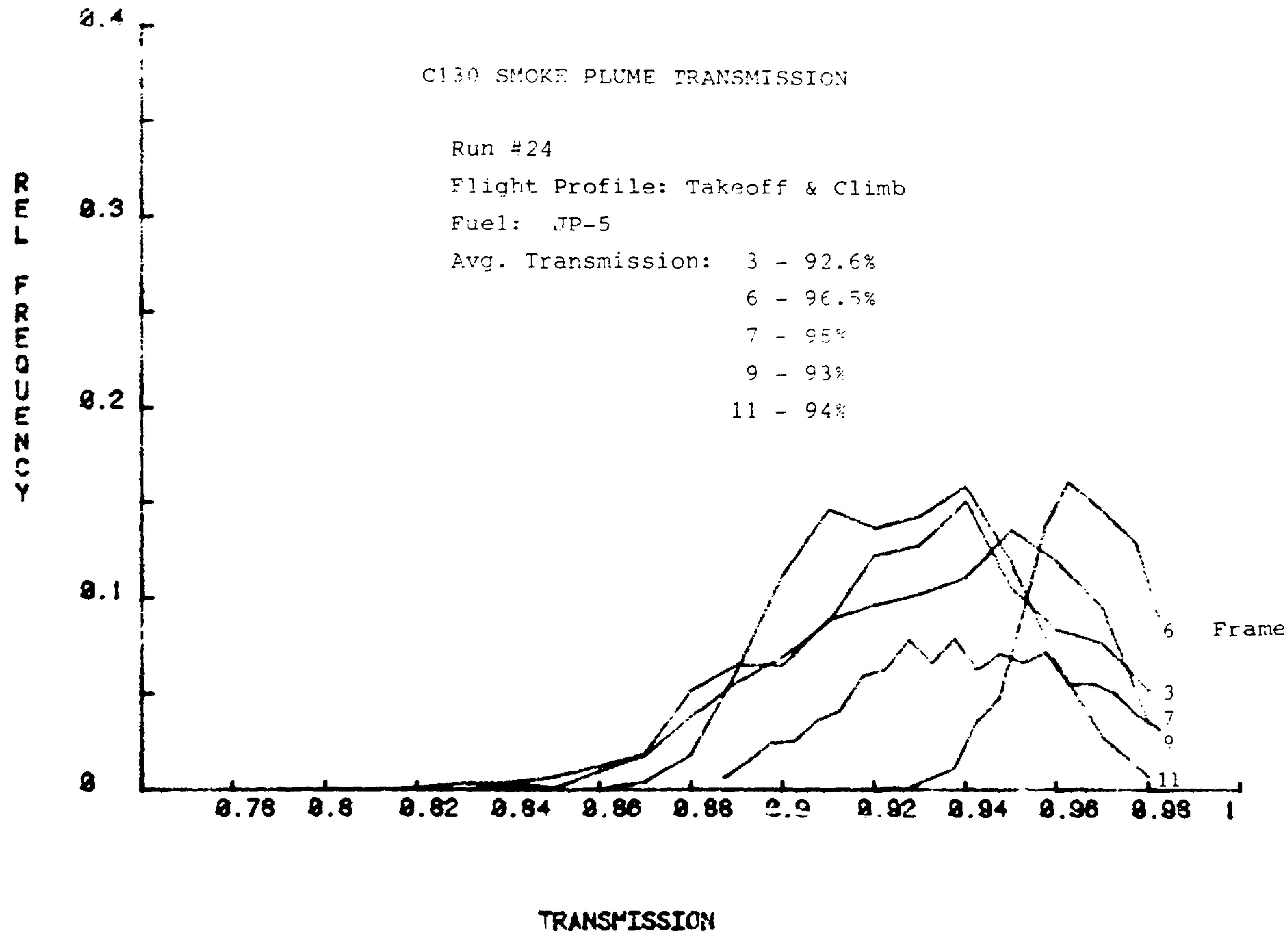


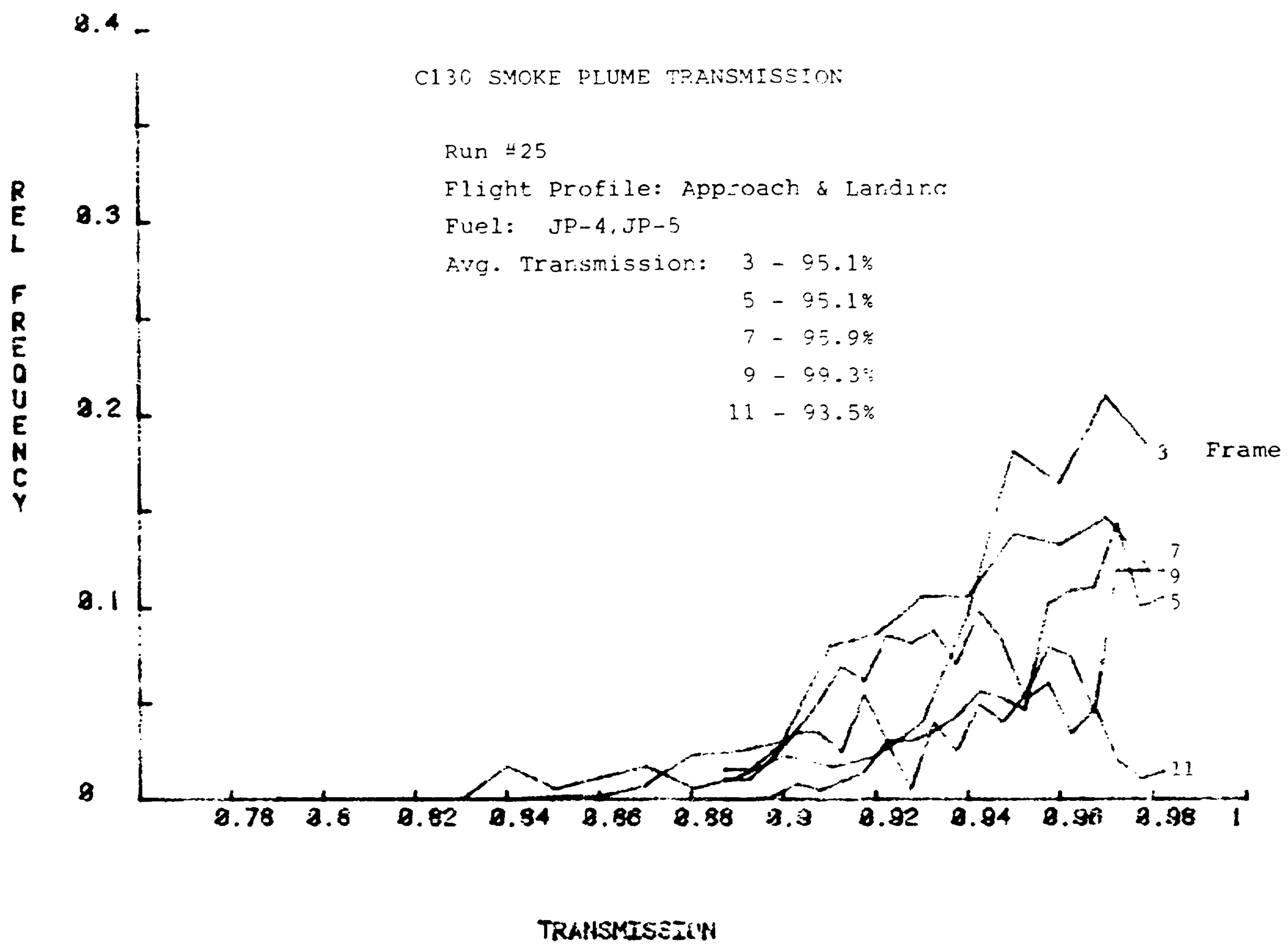
C130 SMOKE PLUME TRANSMISSION
Run #20
Flight Profile: Parallel Pass
Cruise Power
Fuel: JP-5
Avg. Transmission: 1 - 97.6%
4 - 95.6%
5 - 97.4%
7 - 95.6%
Frame
REL FREQUENCY
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION

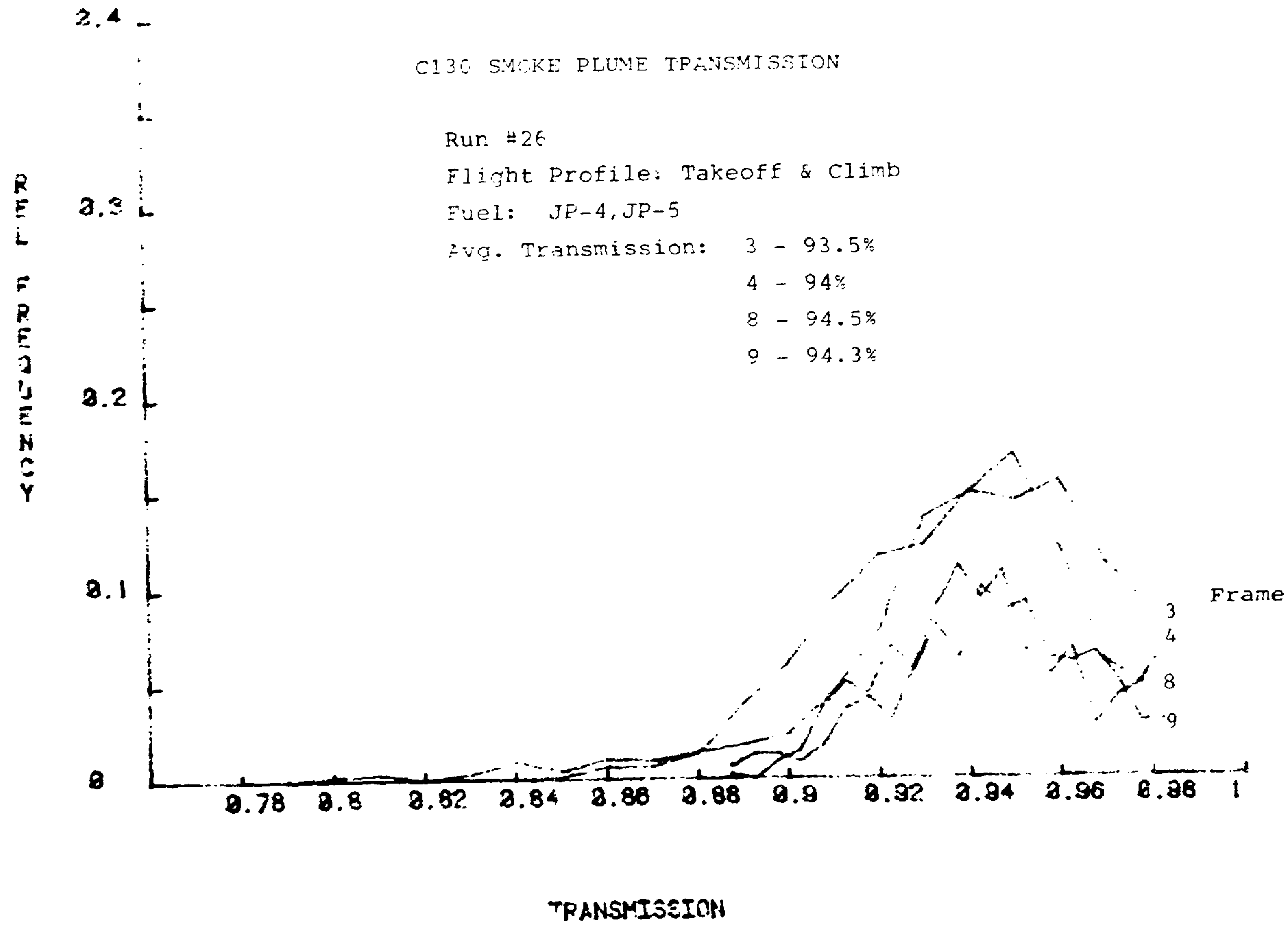

C130 SMOKE PLUME TRANSMISSION
Run #21
Flight Profile: Parallel Pass Climb Power
Fuel: JP-5
Avg. Transmission: 2 - 96%
4 - 96%
REL FREQUENCY
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
2
4
Frame
TRANSMISSION

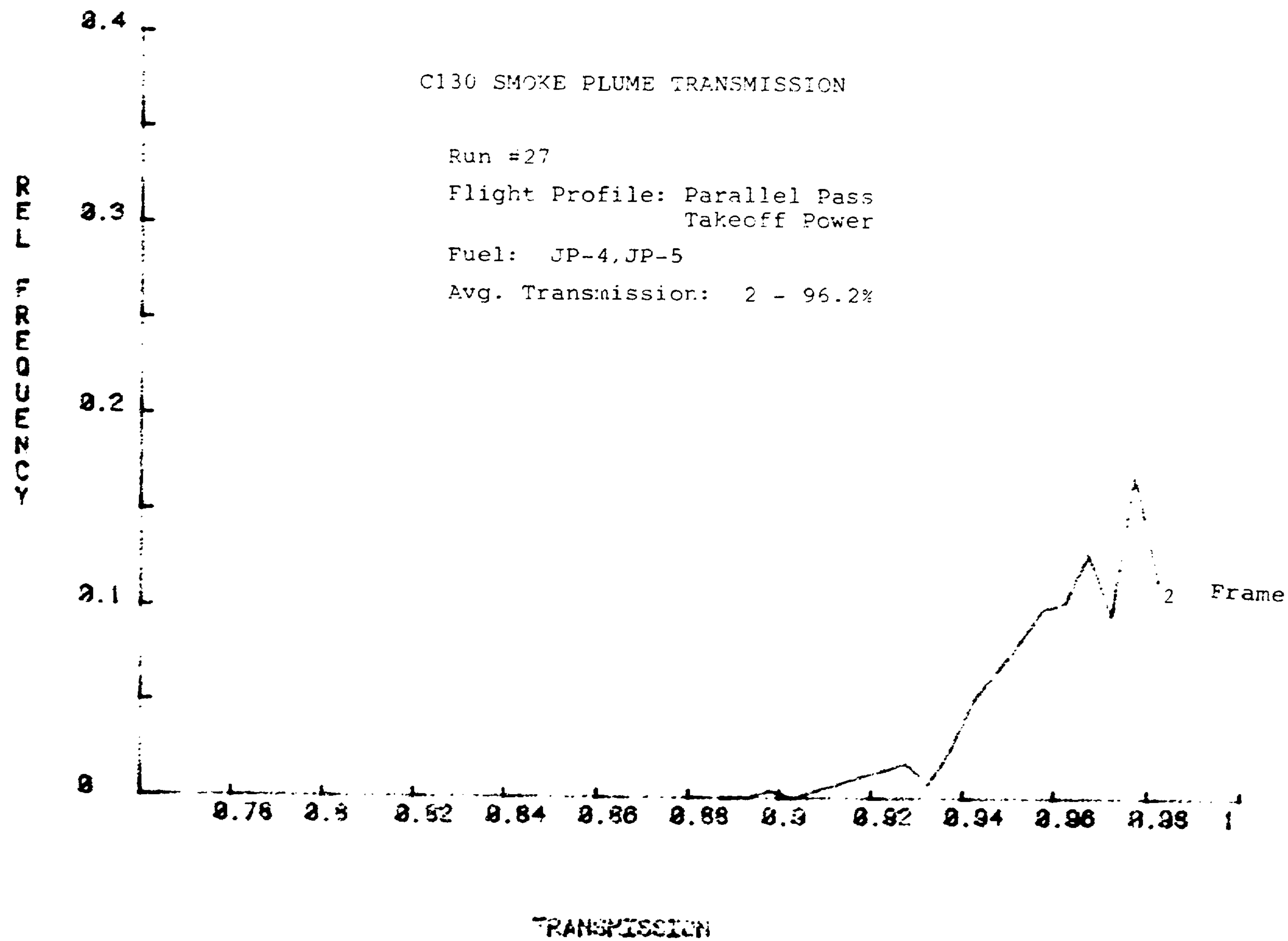

C130 SMOKE PLUME TRANSMISSION
Run #22
Flight Profile: Parallel Pass
Takeoff Power
Fuel: JP-5
Avg. Transmission: 3 - 96.3%
4 - 97.1%
Frame
4
3
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
REL FREQUENCY
TRANSMISSION


C130 SMOKE PLUME TRANSMISSION
Run #23
Flight Profile: Approach & Landing
Fuel: JP-5
Avg. Transmission: 2 - 97.1%
4 - 95.4%
5 - 94.4%
7 - 93.7%
9 - 91.5%
Frame
4
2
7
5
9
REL FREQUENCY
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION

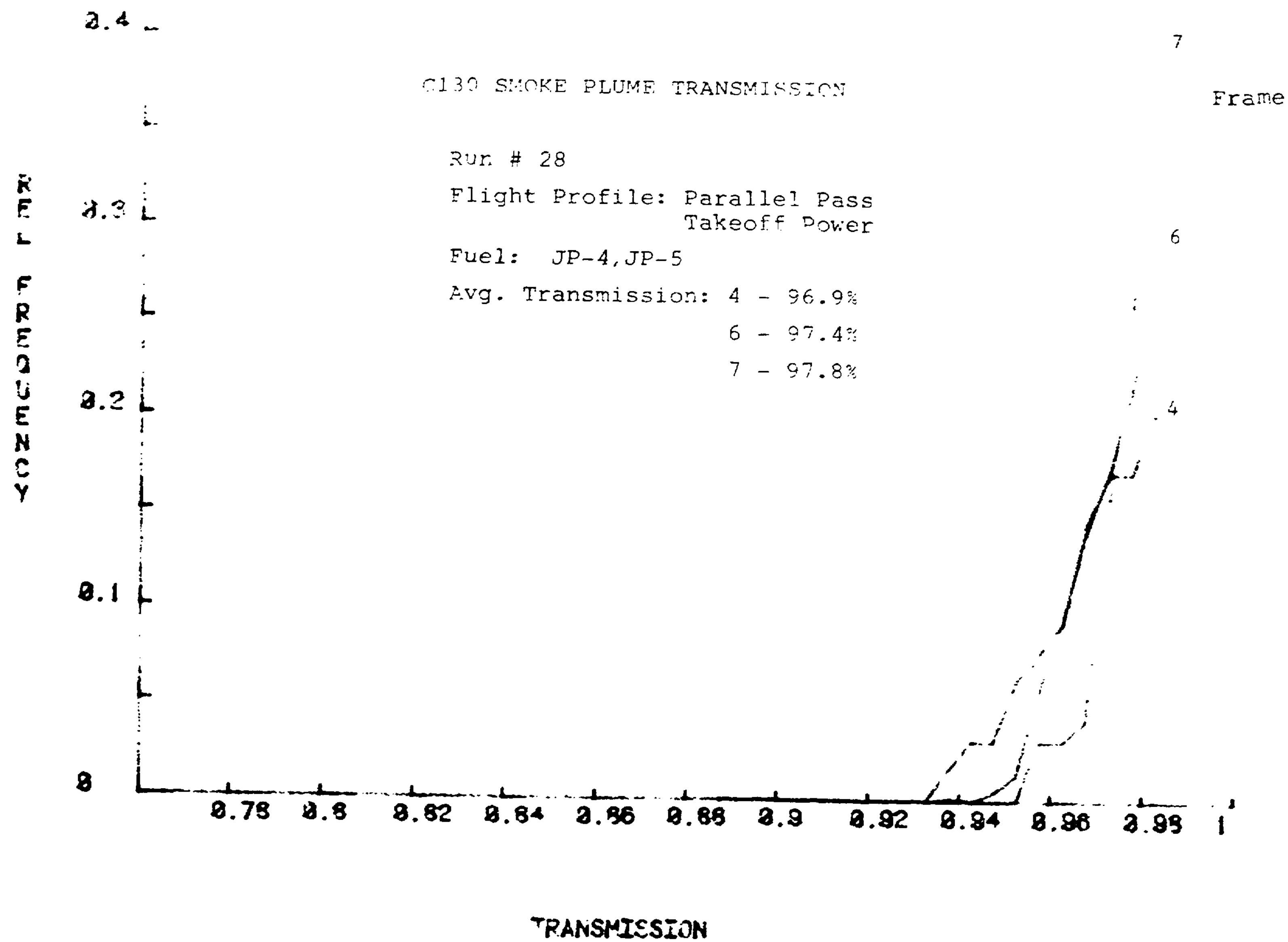

C130 SMOKE PLUME TRANSMISSION
Run #24
Flight Profile: Takeoff & Climb
Fuel: JP-5
Avg. Transmission: 3 - 92.6%
6 - 96.5%
7 - 95%
9 - 93%
11 - 94%
REL FREQUENCY
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION
Frame
6
3
7
9
11


C130 SMOKE PLUME TRANSMISSION
Run #25
Flight Profile: Approach & Landing
Fuel: JP-4,JP-5
Avg. Transmission: 3 - 95.1%
5 - 95.1%
7 - 95.9%
9 - 99.3%
11 - 93.5%
Frame
3
7
9
5
11
REL FREQUENCY
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION


C130 SMOKE PLUME TRANSMISSION
Run #26
Flight Profile: Takeoff & Climb
Fuel: JP-4, JP-5
Avg. Transmission: 3 - 93.5%
4 - 94%
8 - 94.5%
9 - 94.3%
Frame
3
4
8
9
REL FREQUENCY
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION



C130 SMOKE PLUME TRANSMISSION
Run #27
Flight Profile: Parallel Pass
Takeoff Power
Fuel: JP-4, JP-5
Avg. Transmission: 2 - 96.2%
REL FREQUENCY
0.4
0.3
0.2
0.1
0
0.76
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
2
Frame
TRANSMISSION

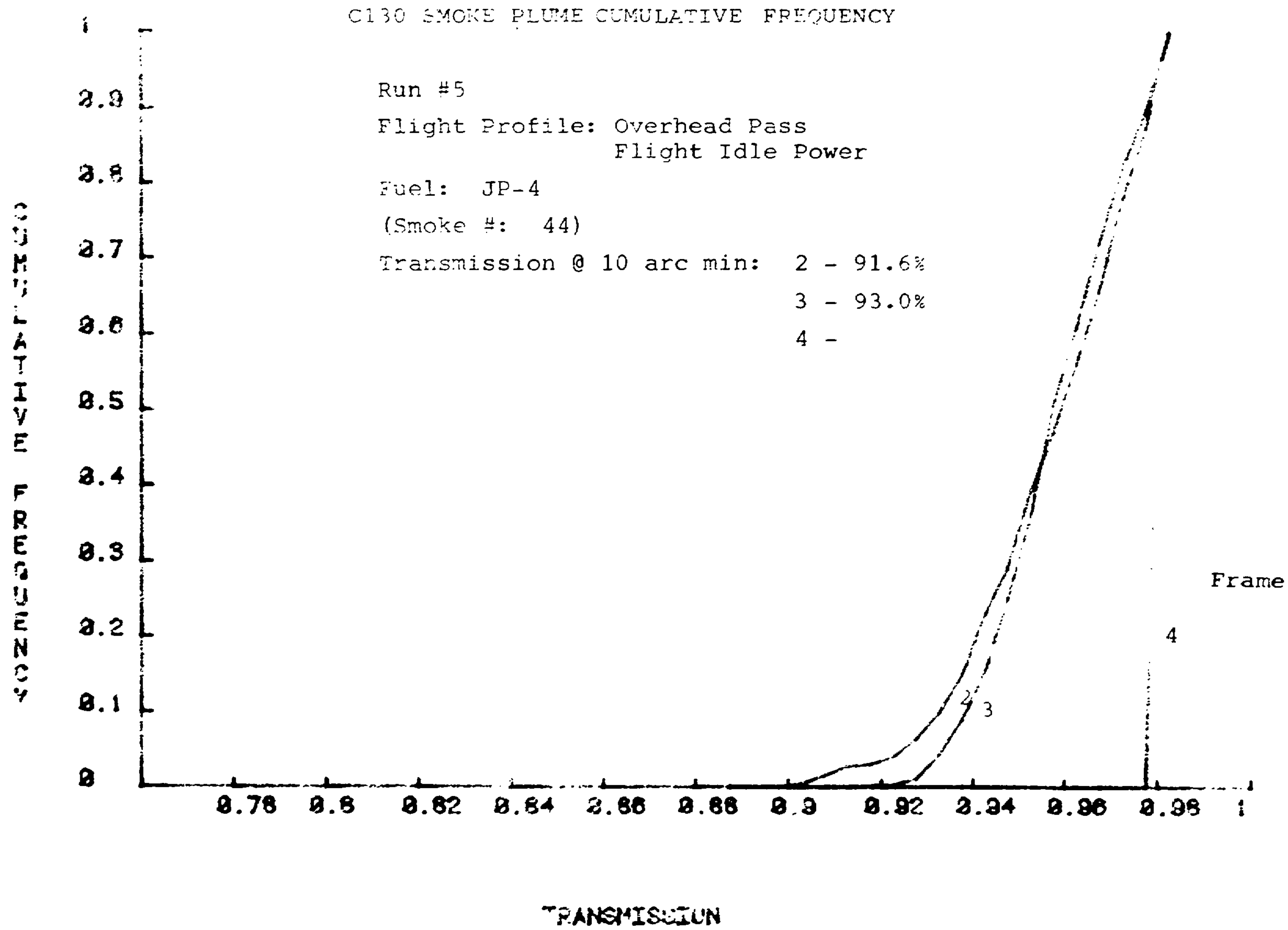


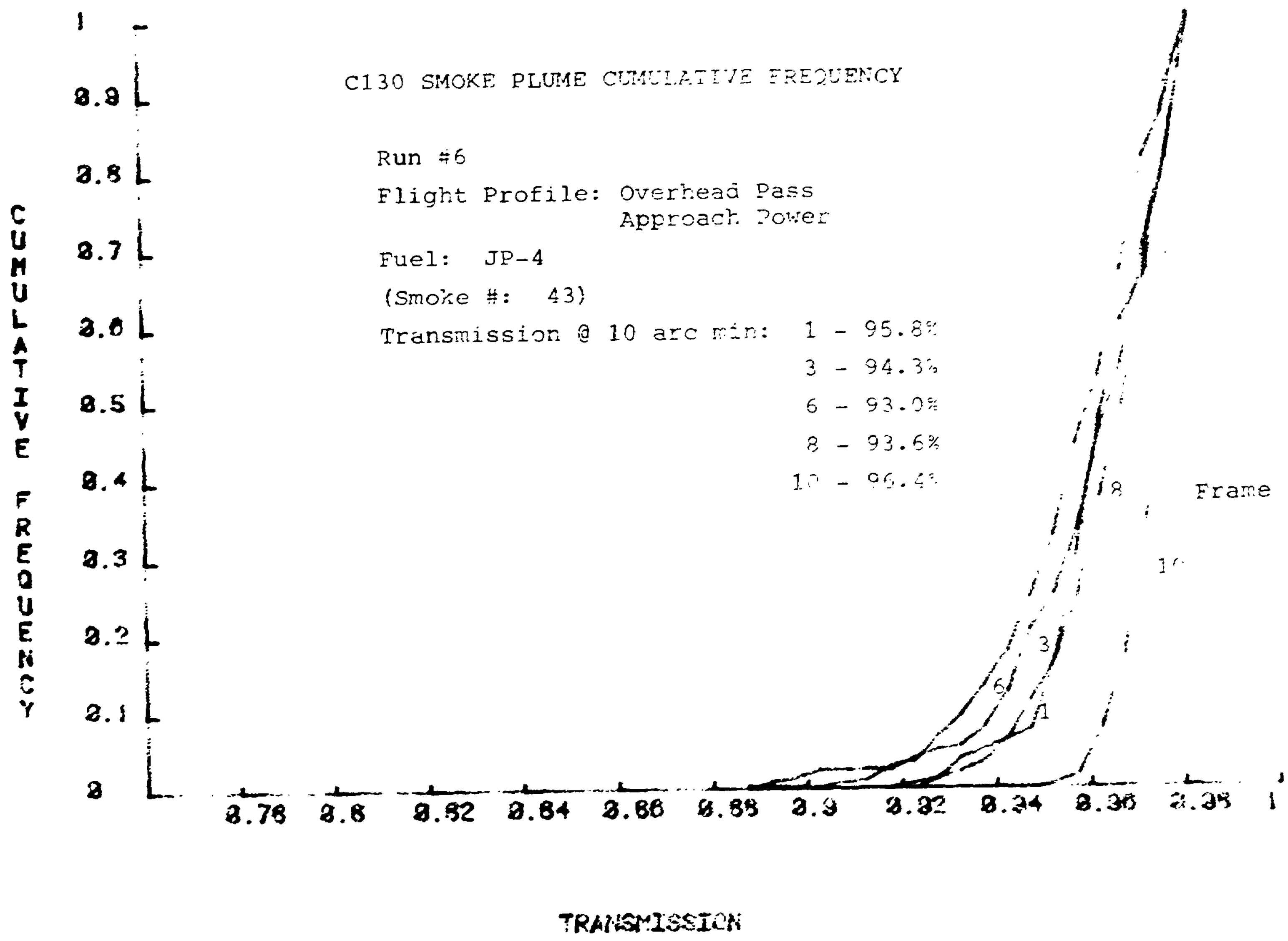
C130 SMOKE PLUME TRANSMISSION
Run # 28
Flight Profile: Parallel Pass
Takeoff Power
Fuel: JP-4,JP-5
Avg. Transmission: 4 - 96.9%
6 - 97.4%
7 - 97.8%
Frame
7
6
4
REL FREQUENCY
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION

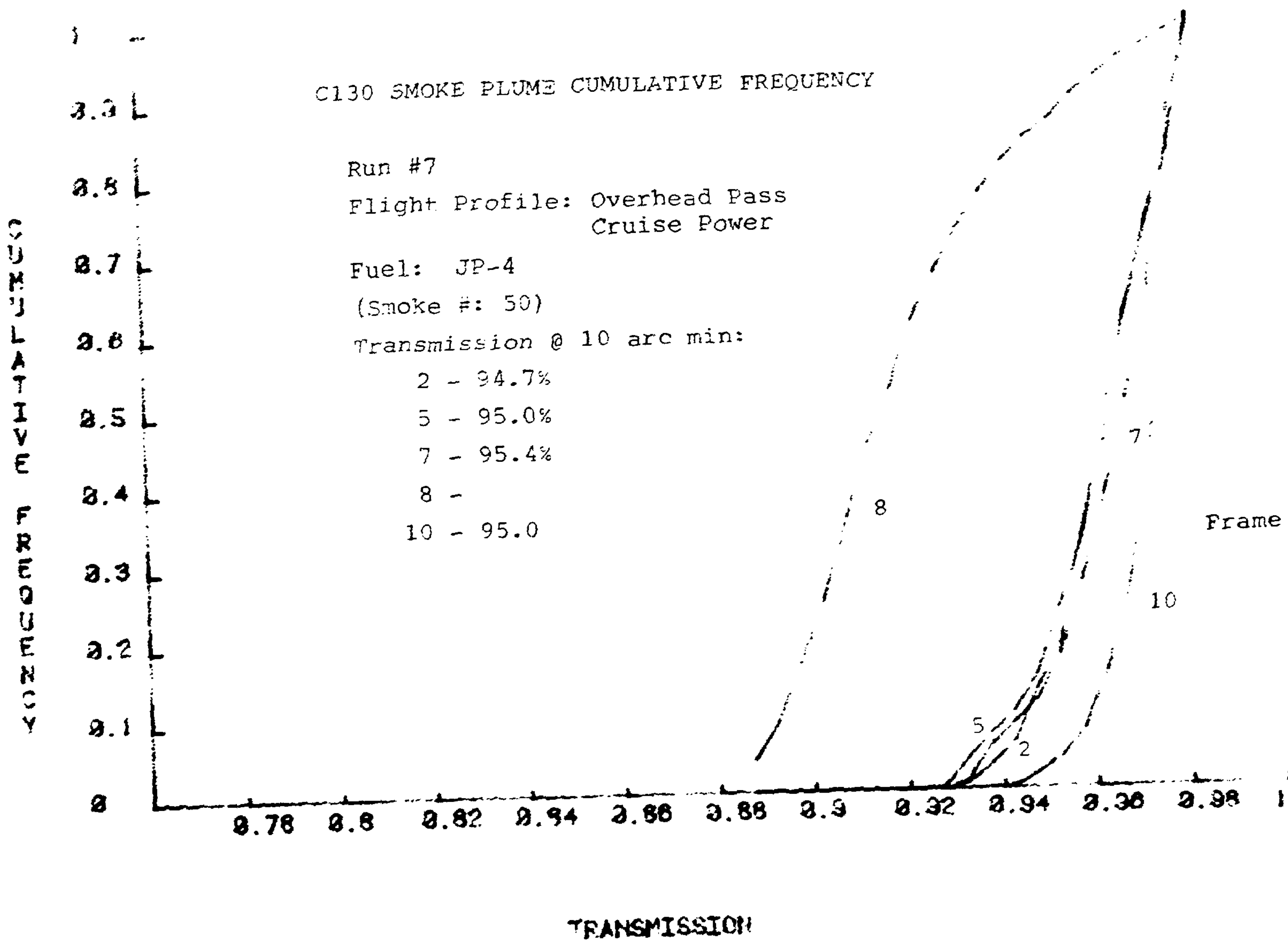
APPENDIX C

TRANSMISSION CUMULATIVE FREQUENCY DATA

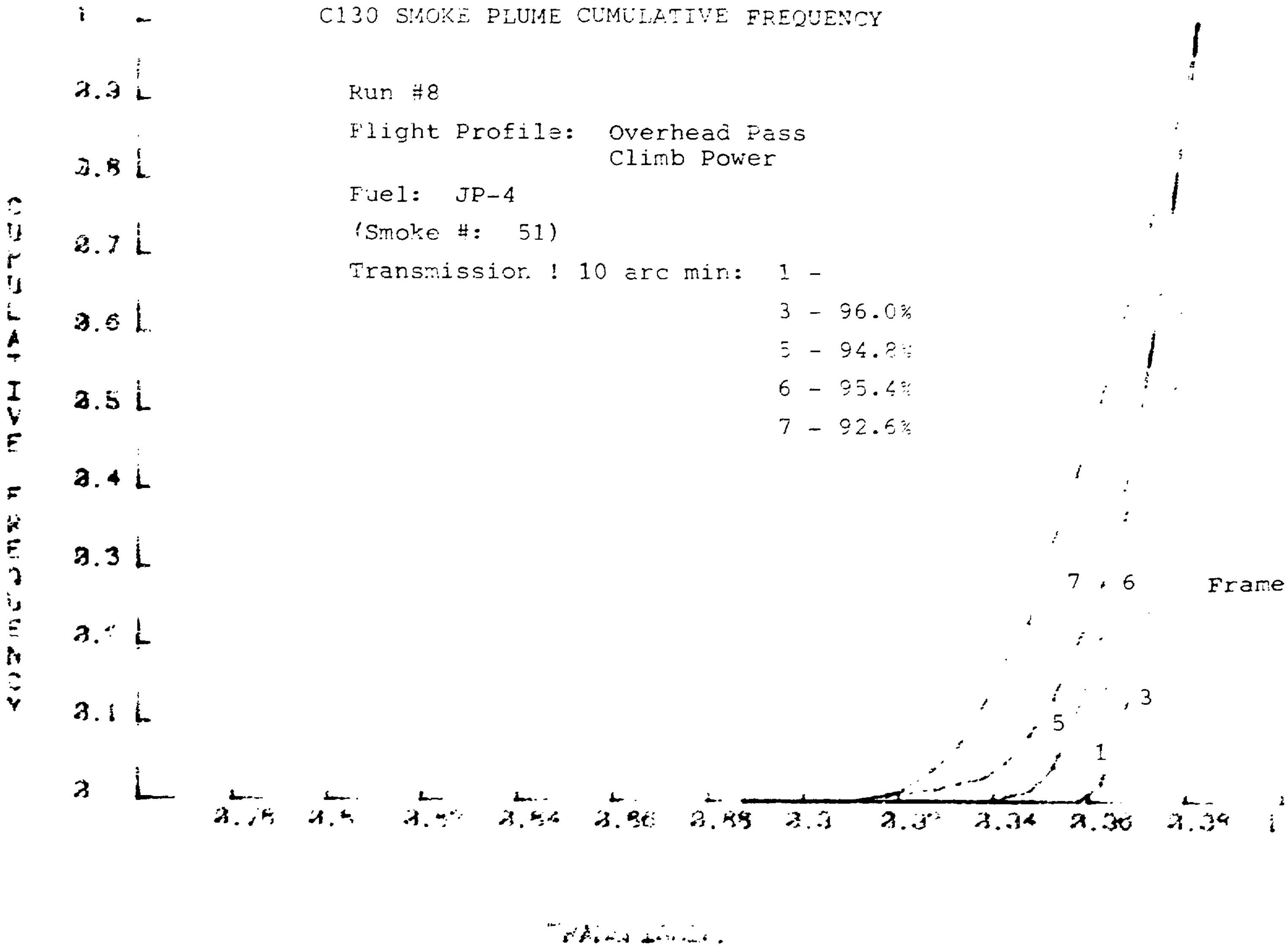
RUNS 5 THROUGH 28


C130 SMOKE PLUME CUMULATIVE FREQUENCY
Run #5
Flight Profile: Overhead Pass
Flight Idle Power
Fuel: JP-4
(Smoke #: 44)
Transmission @ 10 arc min: 2 - 91.6%
3 - 93.0%
4 -
Frame
CUMULATIVE FREQUENCY
TRANSMISSION
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
2
3
4

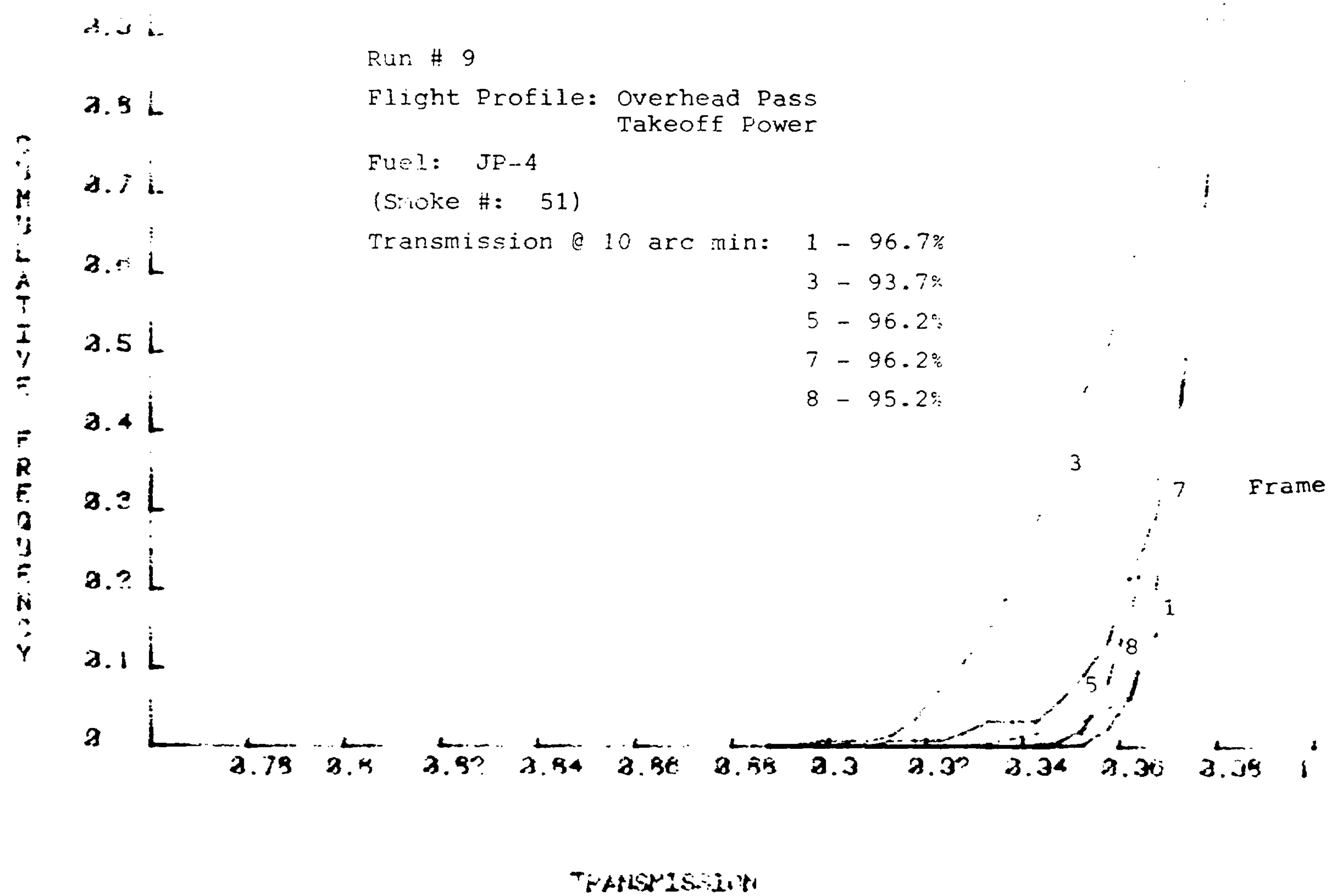

C130 SMOKE PLUME CUMULATIVE FREQUENCY
Run #6
Flight Profile: Overhead Pass
Approach Power
Fuel: JP-4
(Smoke #: 43)
Transmission @ 10 arc min: 1 - 95.8%
3 - 94.3%
6 - 93.0%
8 - 93.6%
10 - 96.4%
Frame
CUMULATIVE FREQUENCY
TRANSMISSION
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

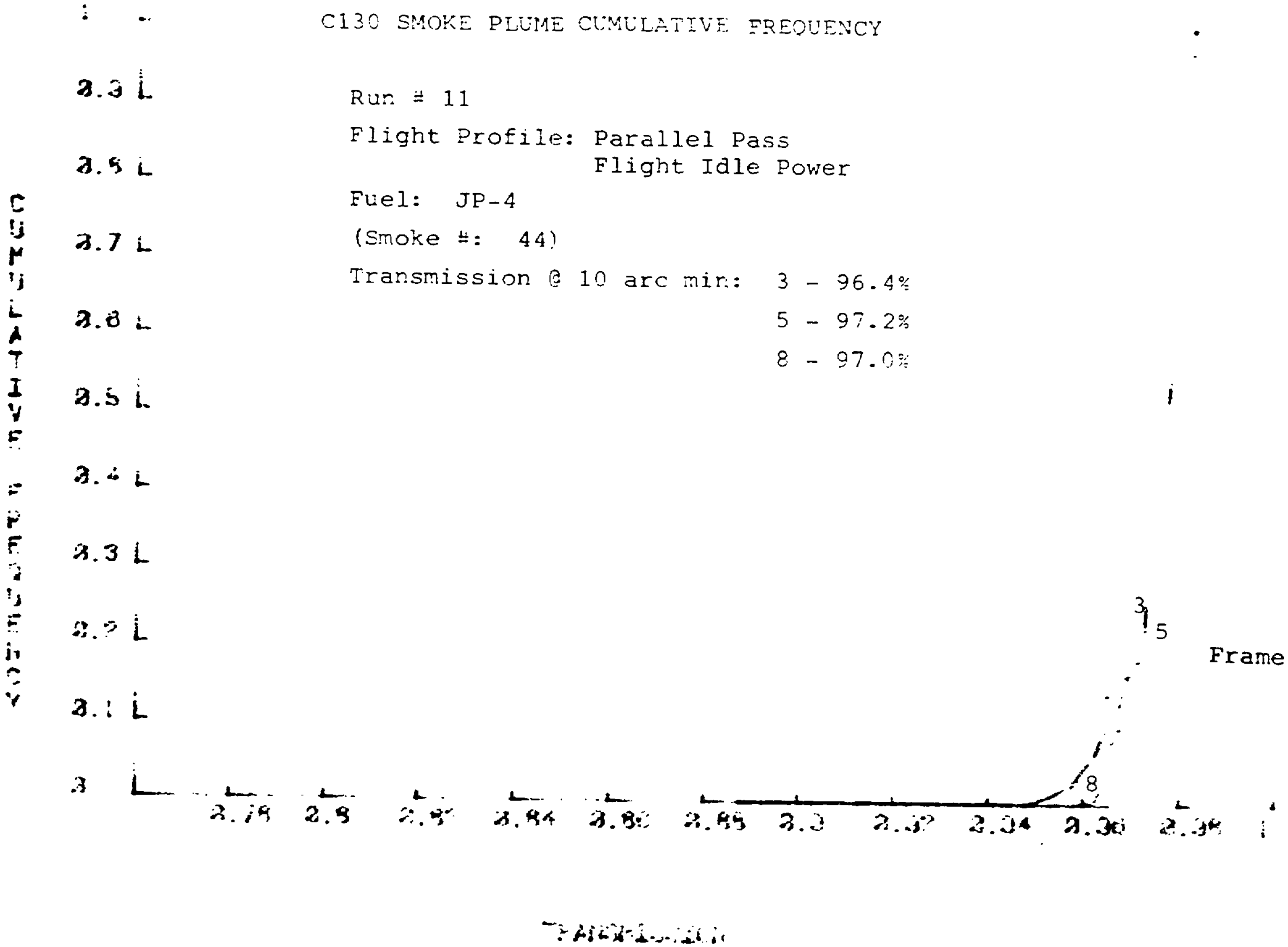


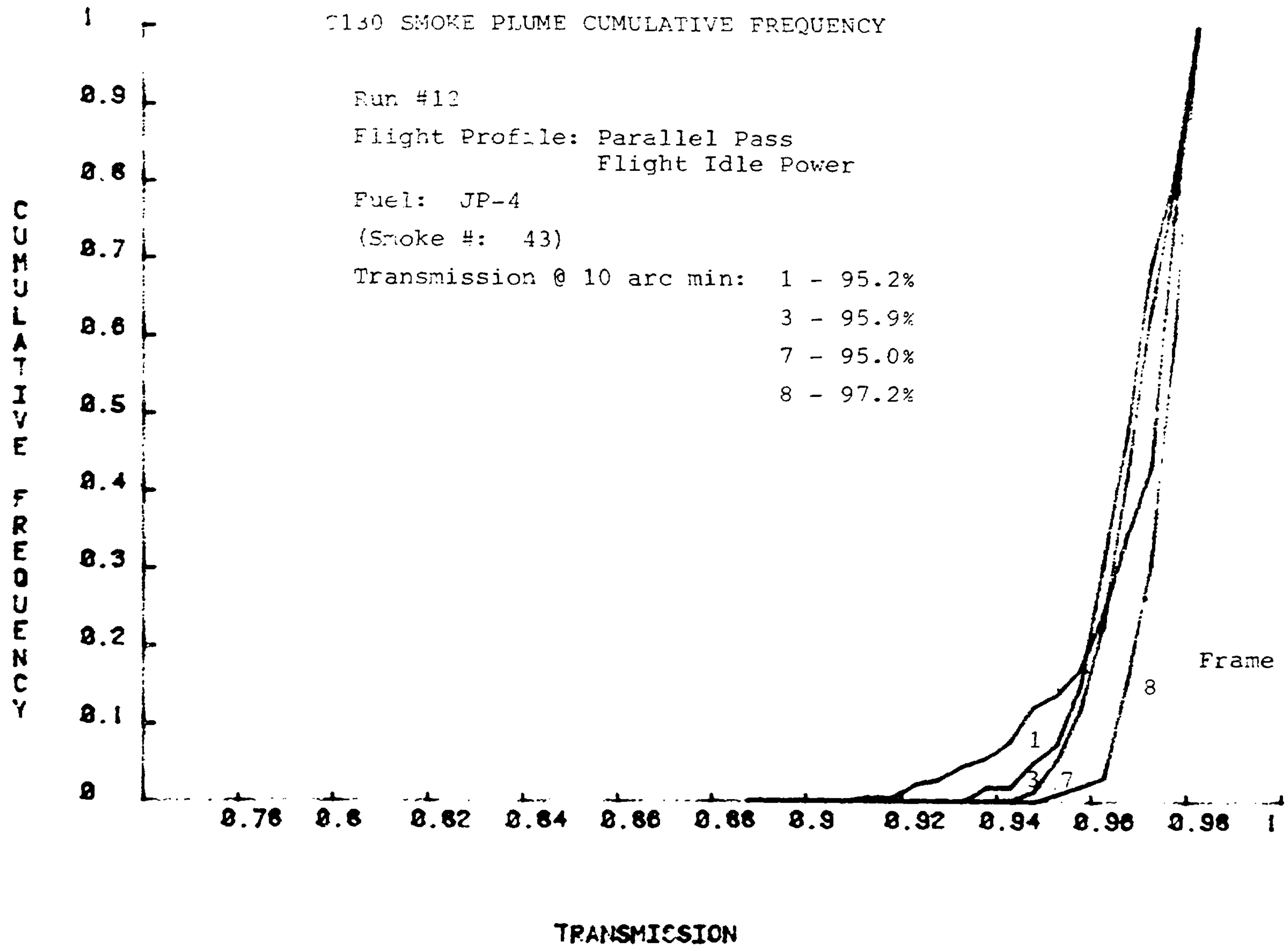
C130 SMOKE PLUME CUMULATIVE FREQUENCY
Run #7
Flight Profile: Overhead Pass
Cruise Power
Fuel: JP-4
(Smoke #: 50)
Transmission @ 10 arc min:
2 - 94.7%
5 - 95.0%
7 - 95.4%
8 -
10 - 95.0
Frame
2
5
7
8
10
CUMULATIVE FREQUENCY
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION

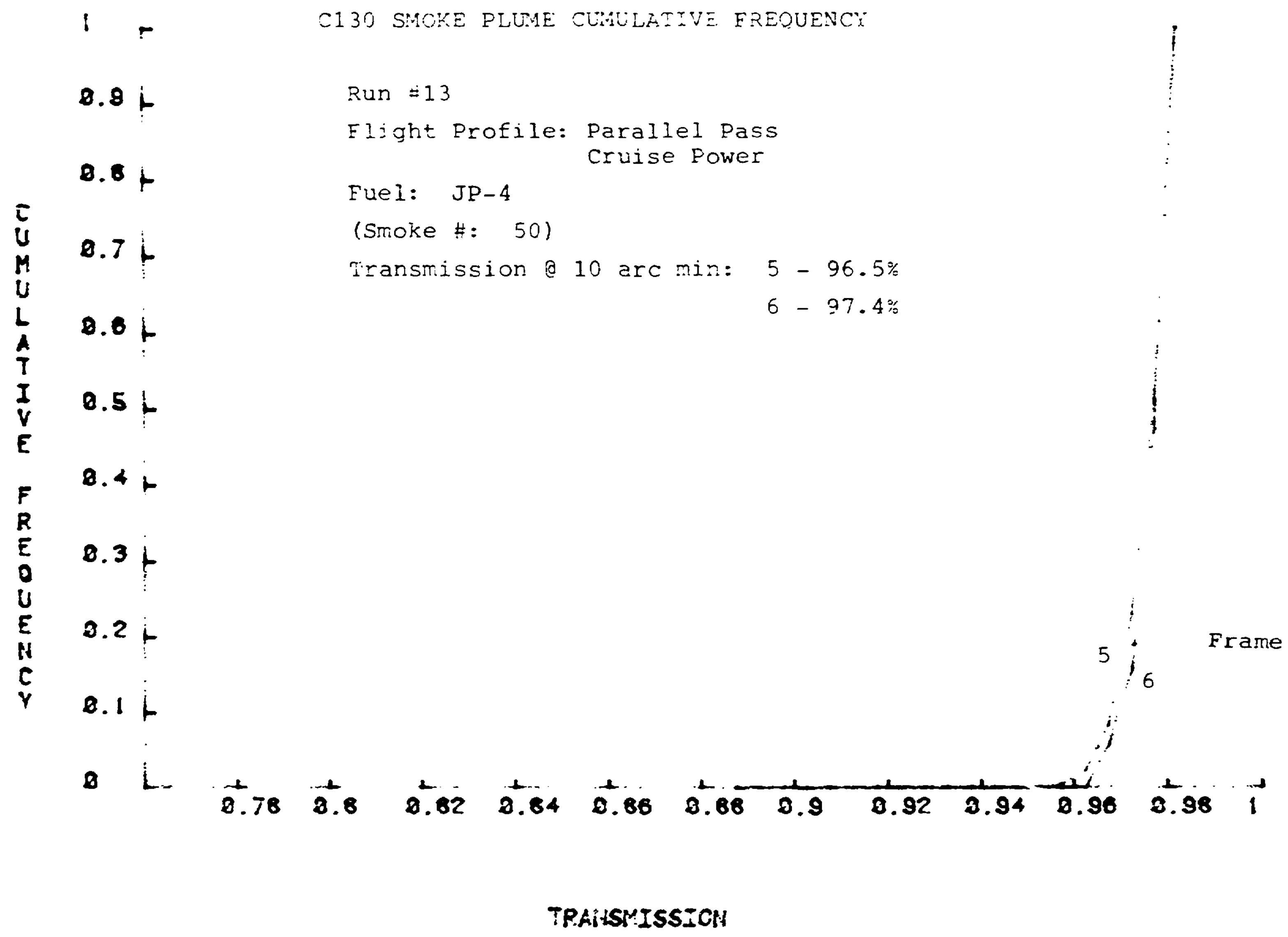

C130 SMOKE PLUME CUMULATIVE FREQUENCY
Run #8
Flight Profile: Overhead Pass
Climb Power
Fuel: JP-4
(Smoke #: 51)
Transmission ! 10 arc min: 1 -
3 - 96.0%
5 - 94.8%
6 - 95.4%
7 - 92.6%
Frame
CUMULATIVE FREQUENCY

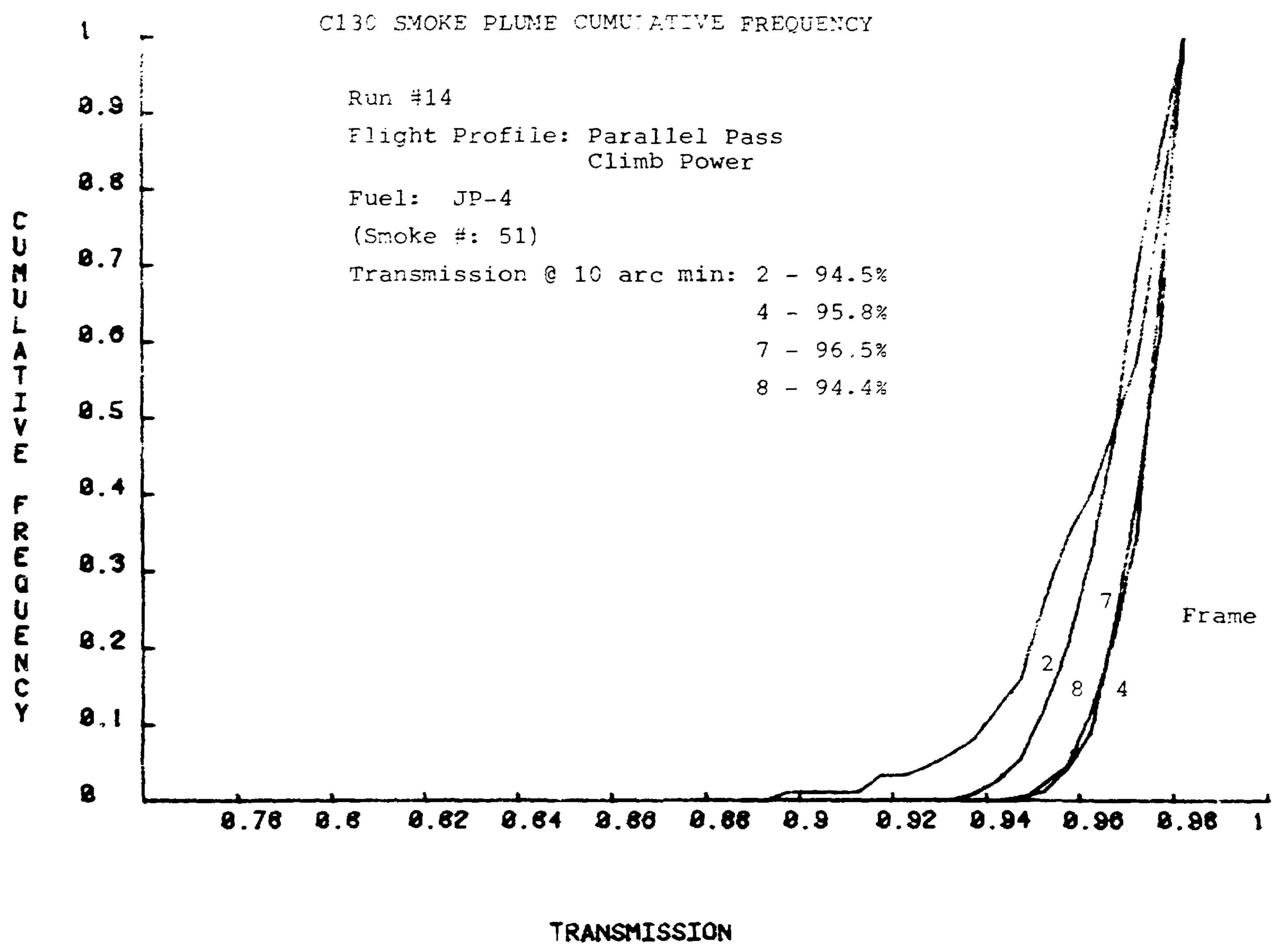
C130 SMOKE PLUME CUMULATIVE FREQUENCY

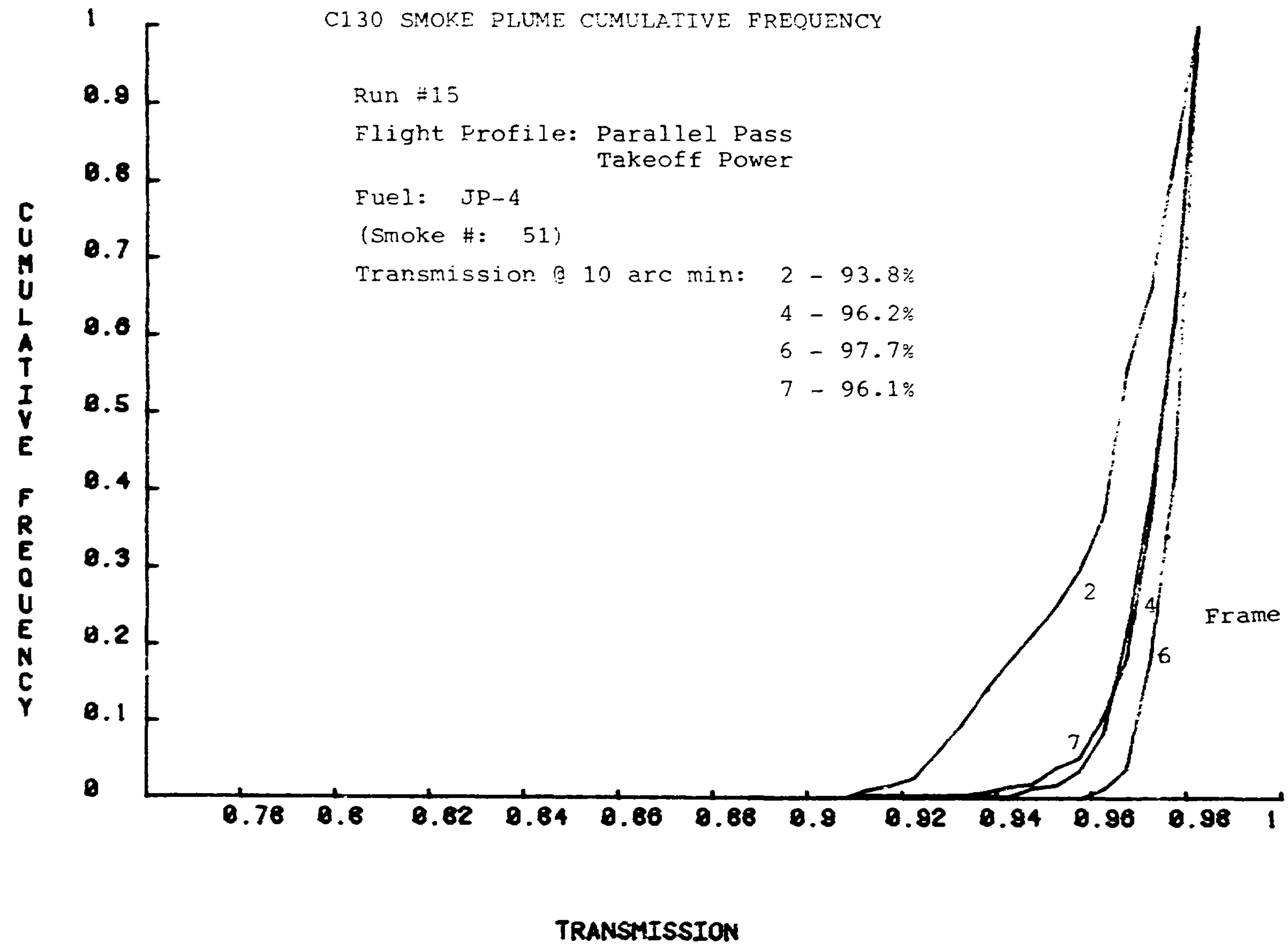



C130 SMOKE PLUME CUMULATIVE FREQUENCY
Run # 11
Flight Profile: Parallel Pass
Flight Idle Power
Fuel: JP-4
(Smoke #: 44)
Transmission @ 10 arc min: 3 - 96.4%
5 - 97.2%
8 - 97.0%
CUMULATIVE FREQUENCY
Frame

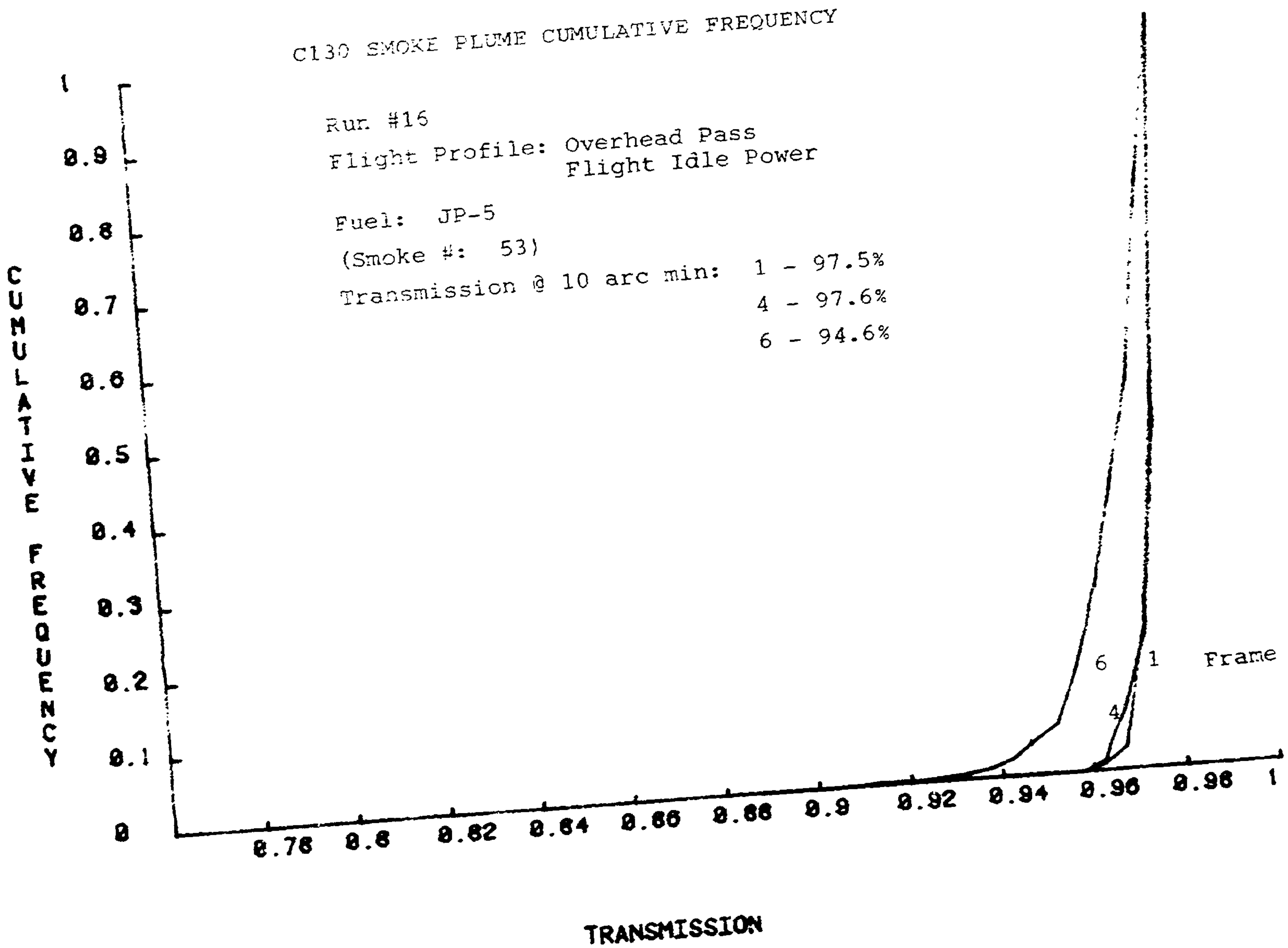

C130 SMOKE PLUME CUMULATIVE FREQUENCY
Run #12
Flight Profile: Parallel Pass
Flight Idle Power
Fuel: JP-4
(Smoke #: 43)
Transmission @ 10 arc min: 1 - 95.2%
3 - 95.9%
7 - 95.0%
8 - 97.2%
Frame
1
3
7
8
CUMULATIVE FREQUENCY
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION

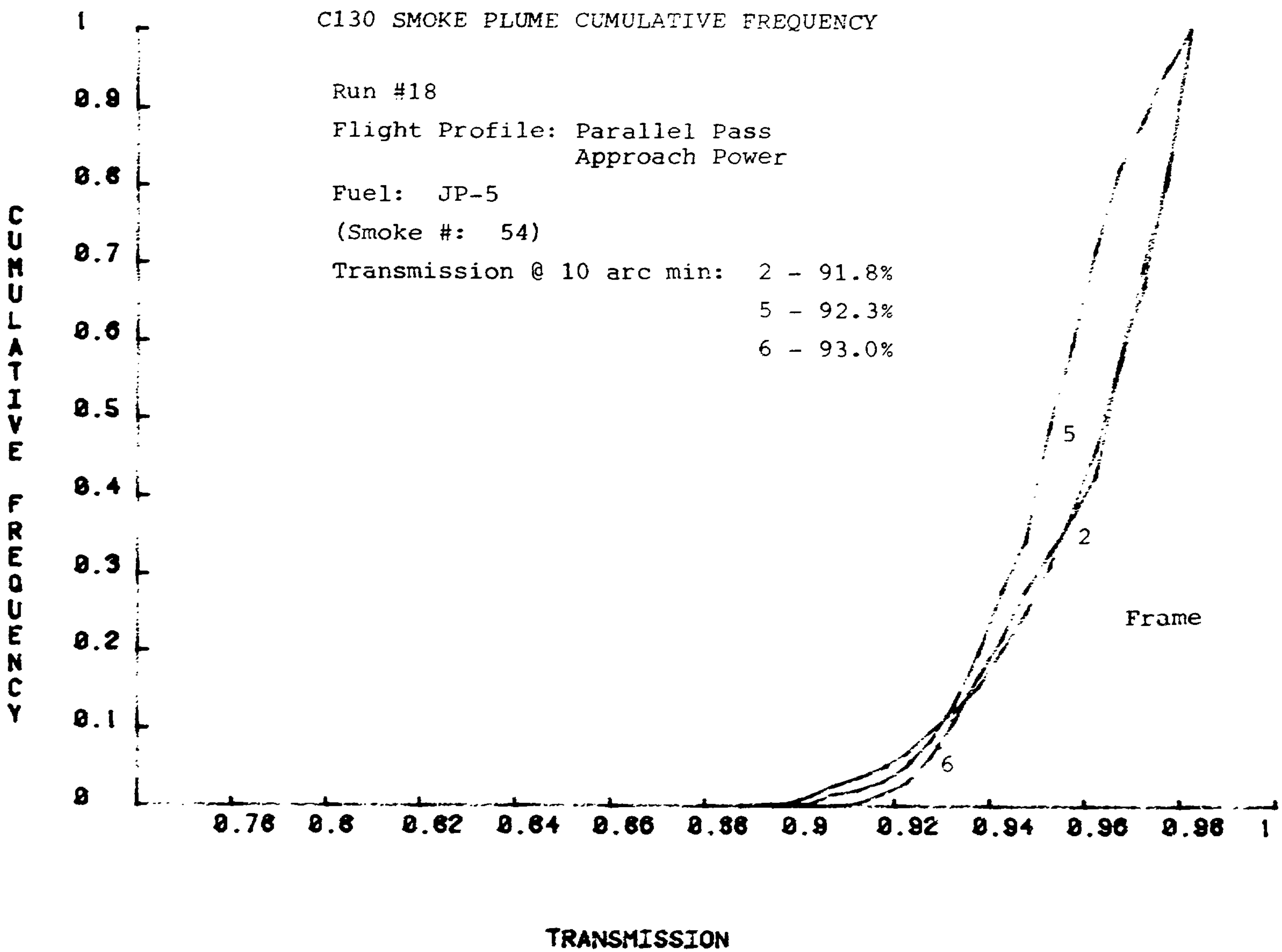

C130 SMOKE PLUME CUMULATIVE FREQUENCY
Run #13
Flight Profile: Parallel Pass
Cruise Power
Fuel: JP-4
(Smoke #: 50)
Transmission @ 10 arc min: 5 - 96.5%
6 - 97.4%
Frame
5
6
CUMULATIVE FREQUENCY
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION

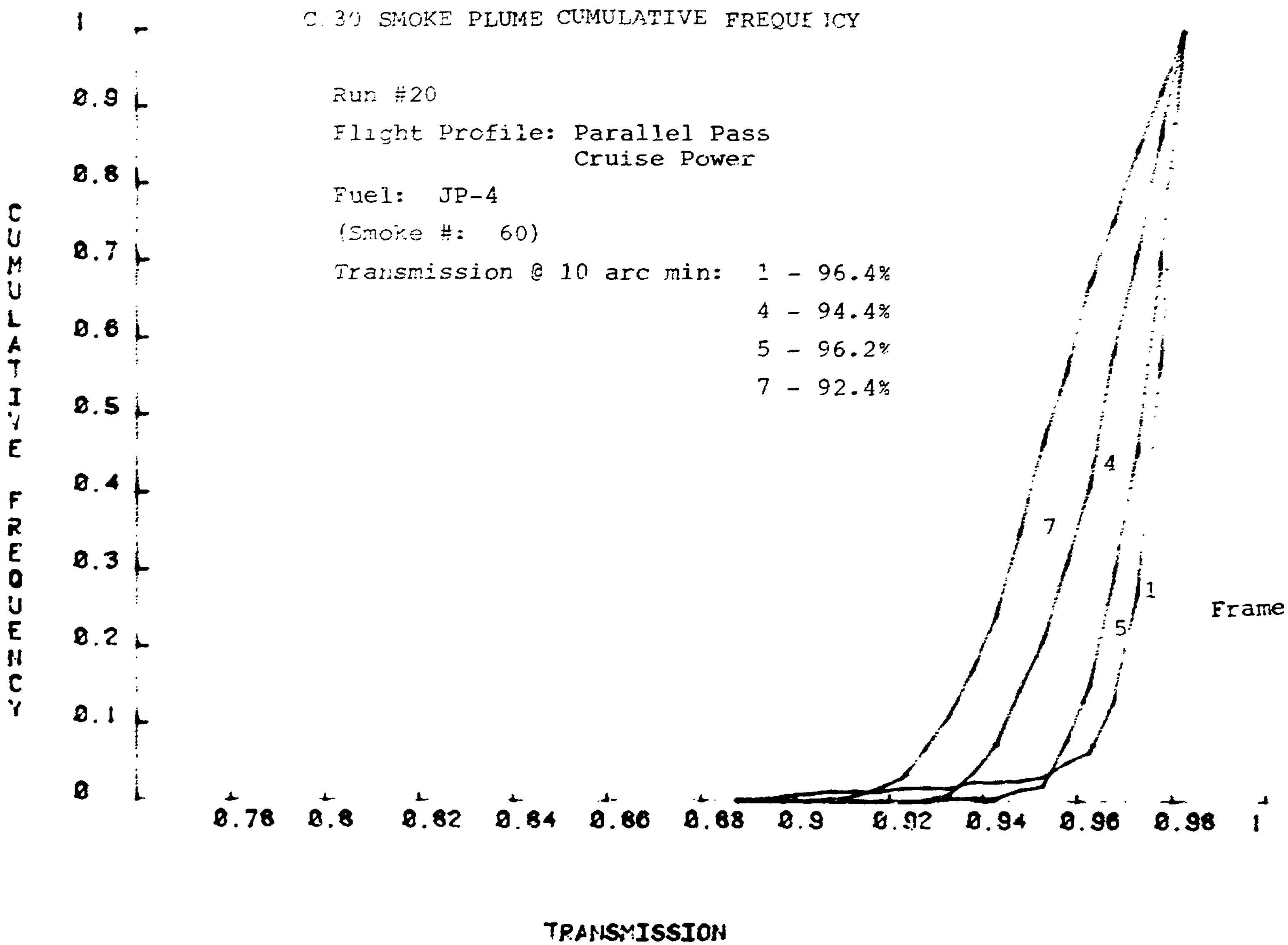

C130 SMOKE PLUME CUMULATIVE FREQUENCY
Run #14
Flight Profile: Parallel Pass
Climb Power
Fuel: JP-4
(Smoke #: 51)
Transmission @ 10 arc min: 2 - 94.5%
4 - 95.8%
7 - 96.5%
8 - 94.4%
Frame
2
8
7
4
CUMULATIVE FREQUENCY
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION

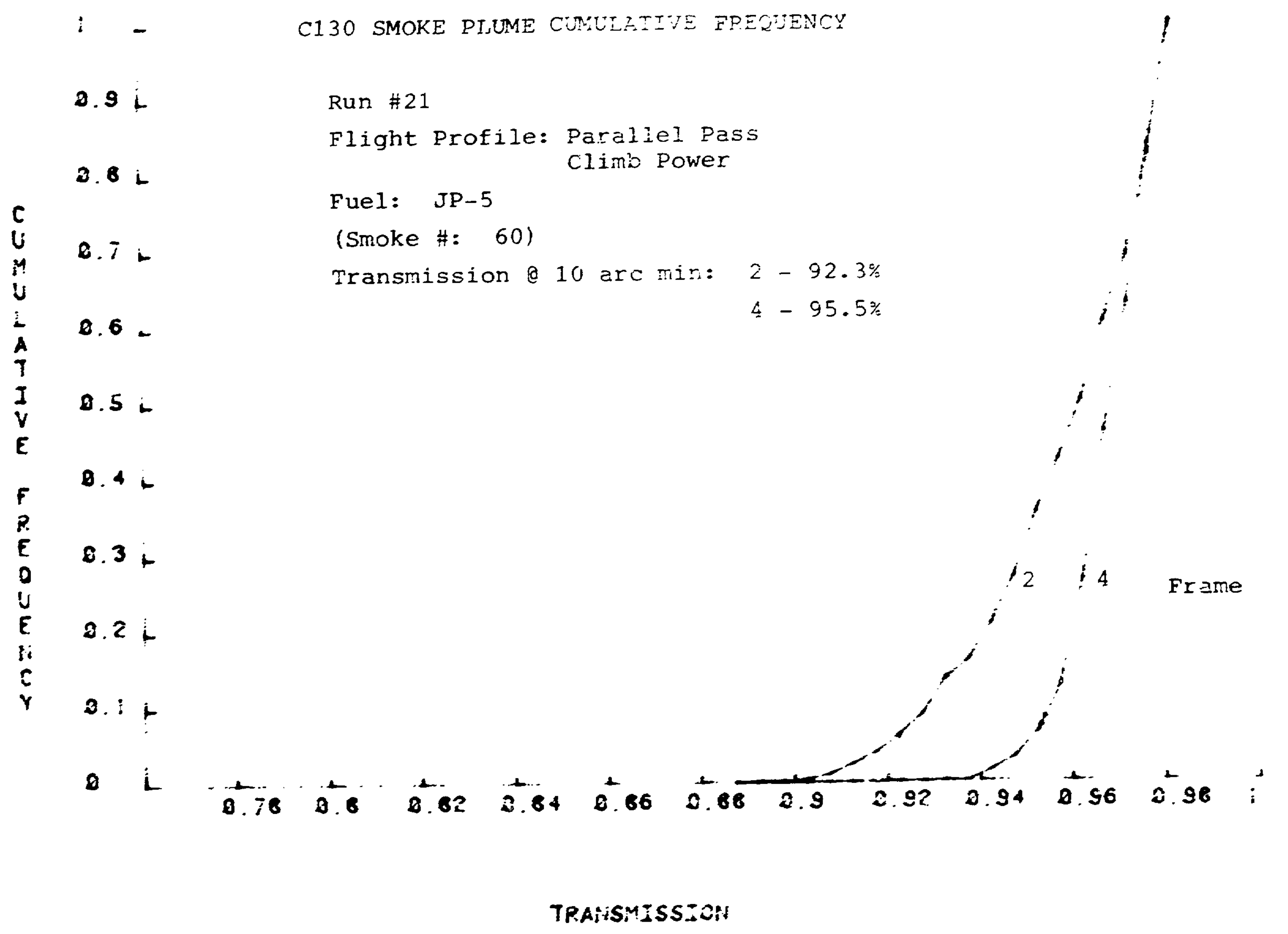


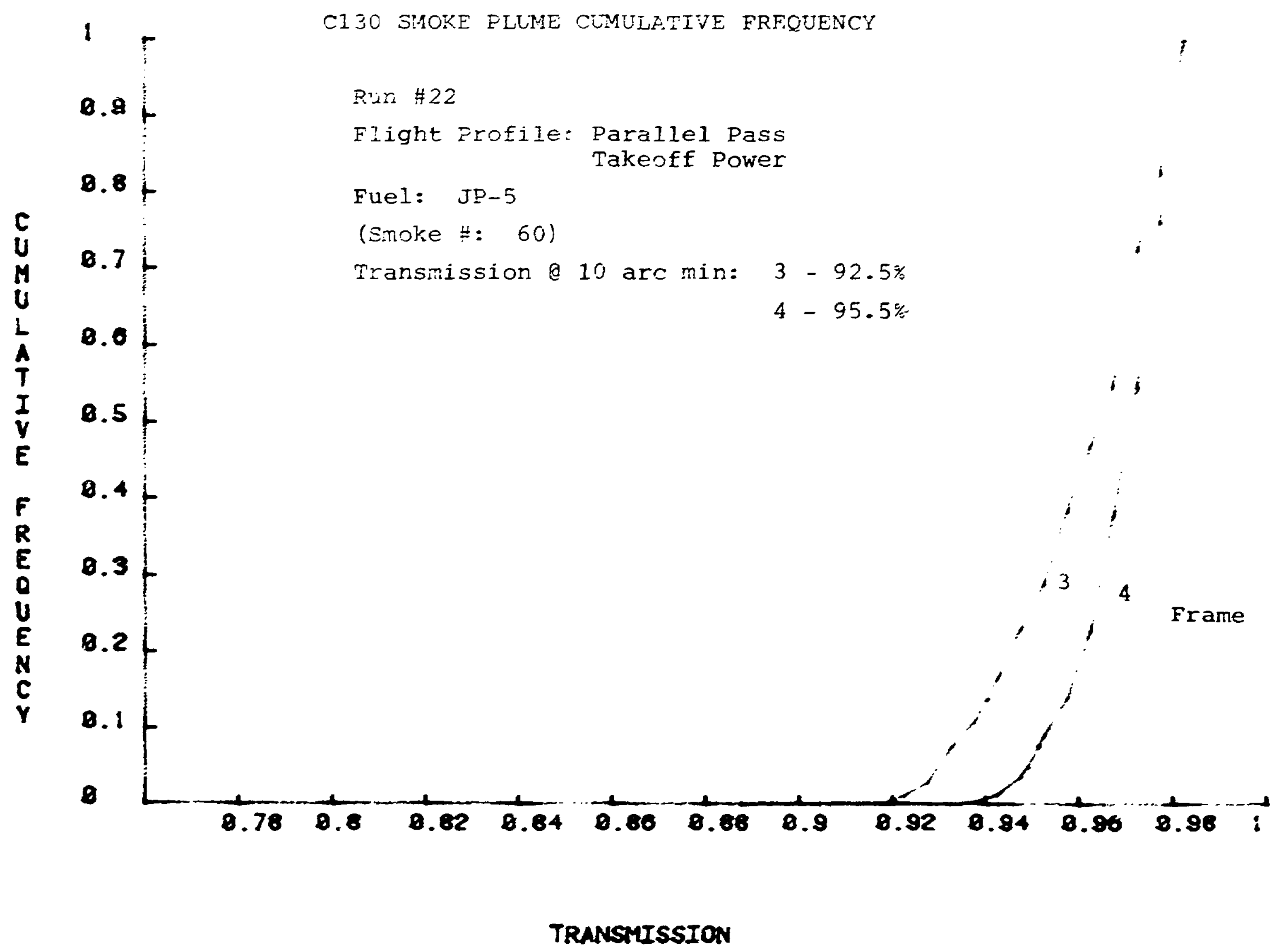
C130 SMOKE PLUME CUMULATIVE FREQUENCY
Run #15
Flight Profile: Parallel Pass
Takeoff Power
Fuel: JP-4
(Smoke #: 51)
Transmission @ 10 arc min: 2 - 93.8%
4 - 96.2%
6 - 97.7%
7 - 96.1%
CUMULATIVE FREQUENCY
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION
2
4
6
7
Frame

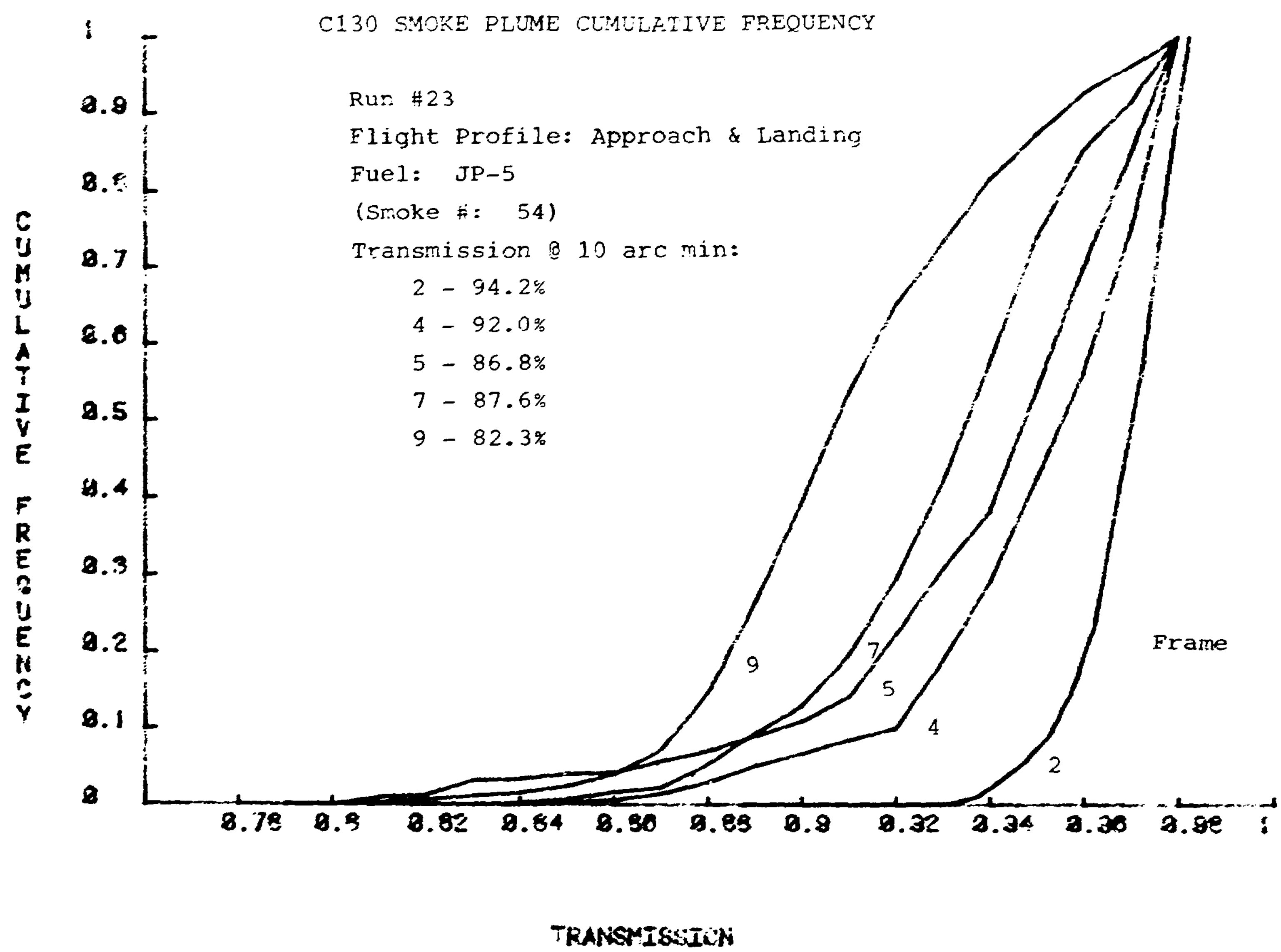

C130 SMOKE PLUME CUMULATIVE FREQUENCY
Run #16
Flight Profile: Overhead Pass
Flight Idle Power
Fuel: JP-5
(Smoke #: 53)
Transmission @ 10 arc min: 1 - 97.5%
4 - 97.6%
6 - 94.6%
Frame
6
4
1
CUMULATIVE FREQUENCY
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
TRANSMISSION
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1


C130 SMOKE PLUME CUMULATIVE FREQUENCY
Run #18
Flight Profile: Parallel Pass
Approach Power
Fuel: JP-5
(Smoke #: 54)
Transmission @ 10 arc min: 2 - 91.8%
5 - 92.3%
6 - 93.0%
Frame
5
2
6
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.76
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
CUMULATIVE FREQUENCY
TRANSMISSION

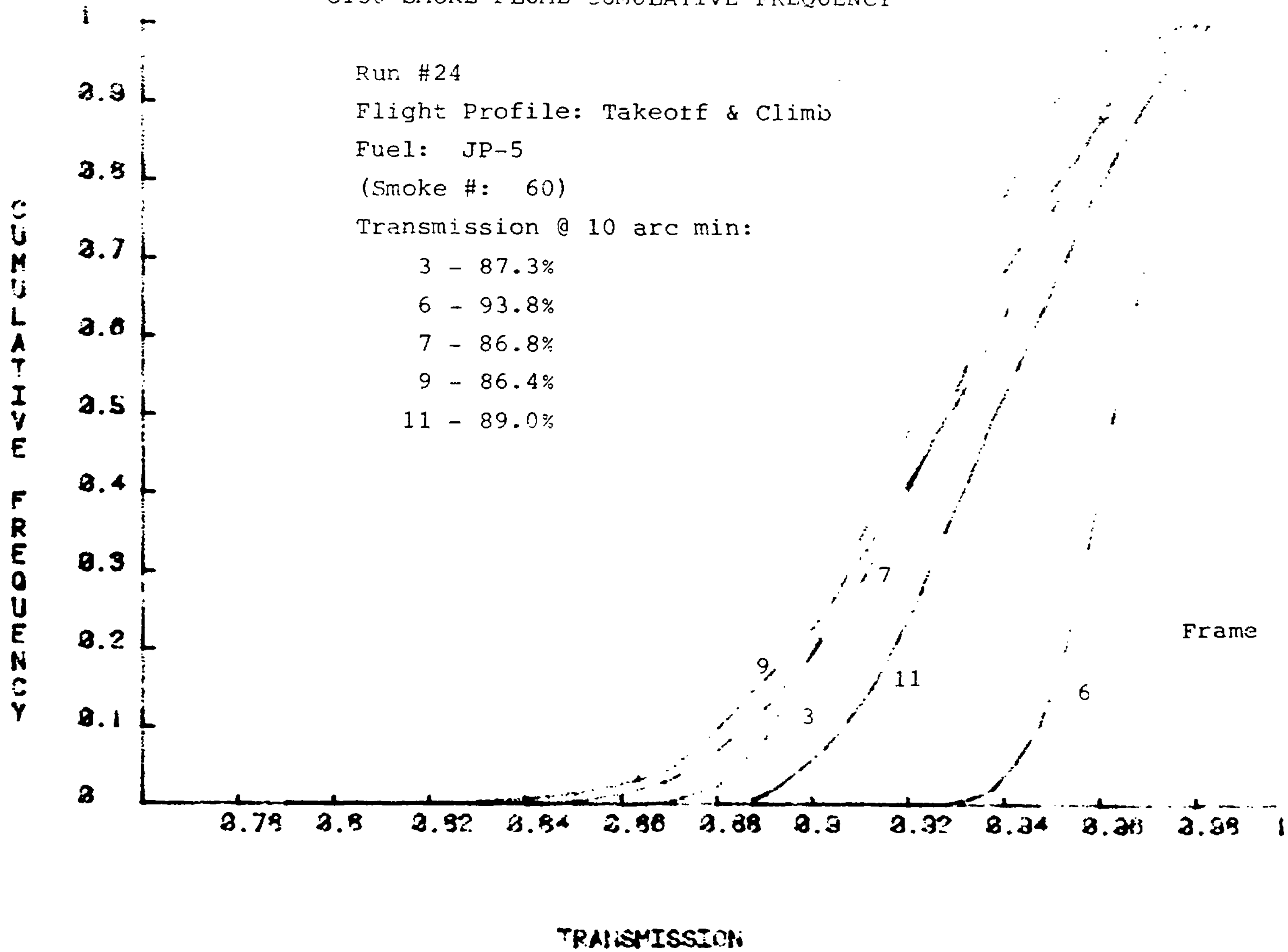

C.30 SMOKE PLUME CUMULATIVE FREQUENCY
Run #20
Flight Profile: Parallel Pass
Cruise Power
Fuel: JP-4
(Smoke #: 60)
Transmission @ 10 arc min: 1 - 96.4%
4 - 94.4%
5 - 96.2%
7 - 92.4%
CUMULATIVE FREQUENCY
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION
Frame
1
4
5
7

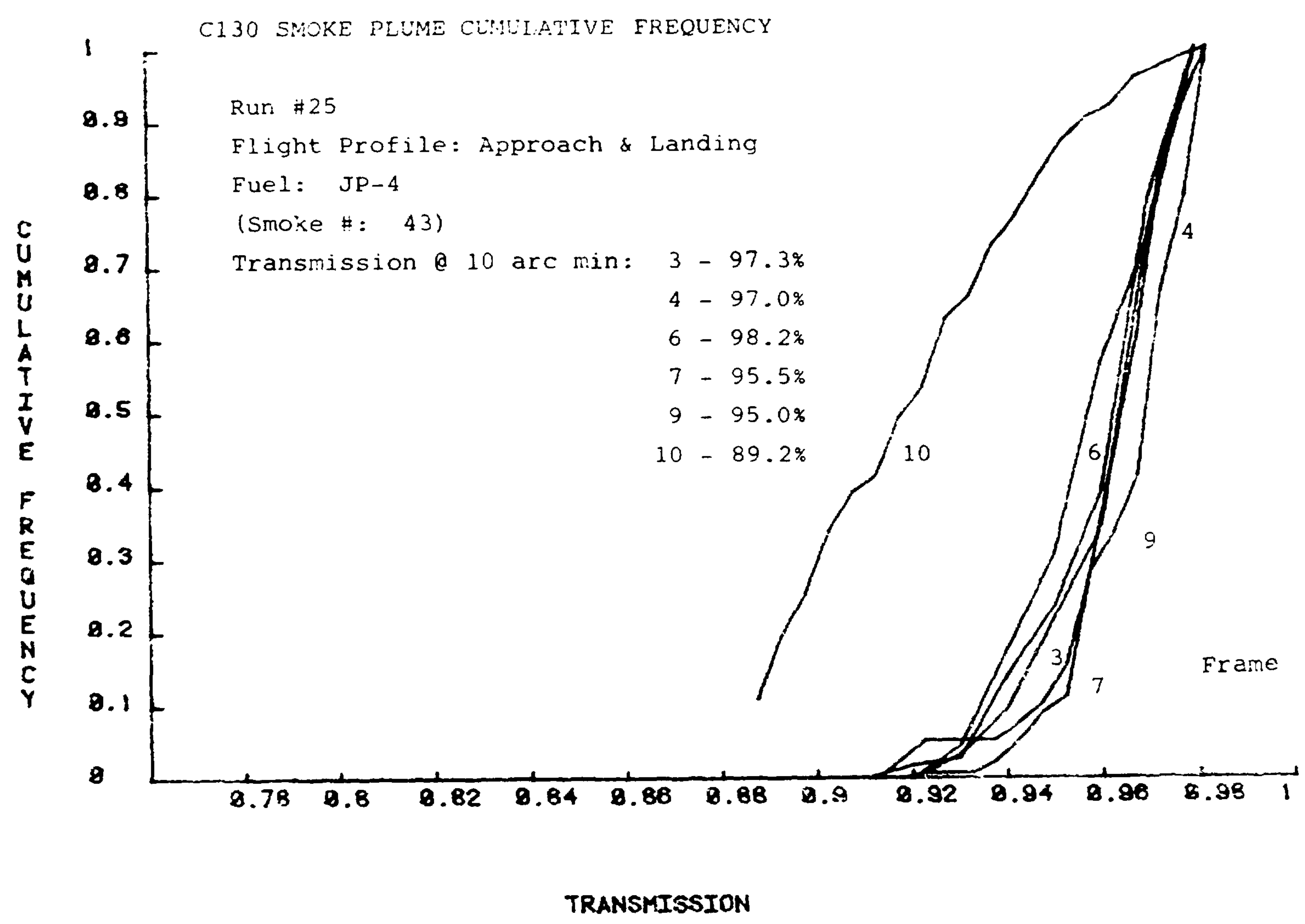

C130 SMOKE PLUME CUMULATIVE FREQUENCY
Run #21
Flight Profile: Parallel Pass
Climb Power
Fuel: JP-5
(Smoke #: 60)
Transmission @ 10 arc min: 2 - 92.3%
4 - 95.5%
2
4
Frame
CUMULATIVE FREQUENCY
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION


C130 SMOKE PLUME CUMULATIVE FREQUENCY
Run #22
Flight Profile: Parallel Pass
Takeoff Power
Fuel: JP-5
(Smoke #: 60)
Transmission @ 10 arc min: 3 - 92.5%
4 - 95.5%
3
4
Frame
CUMULATIVE FREQUENCY
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION

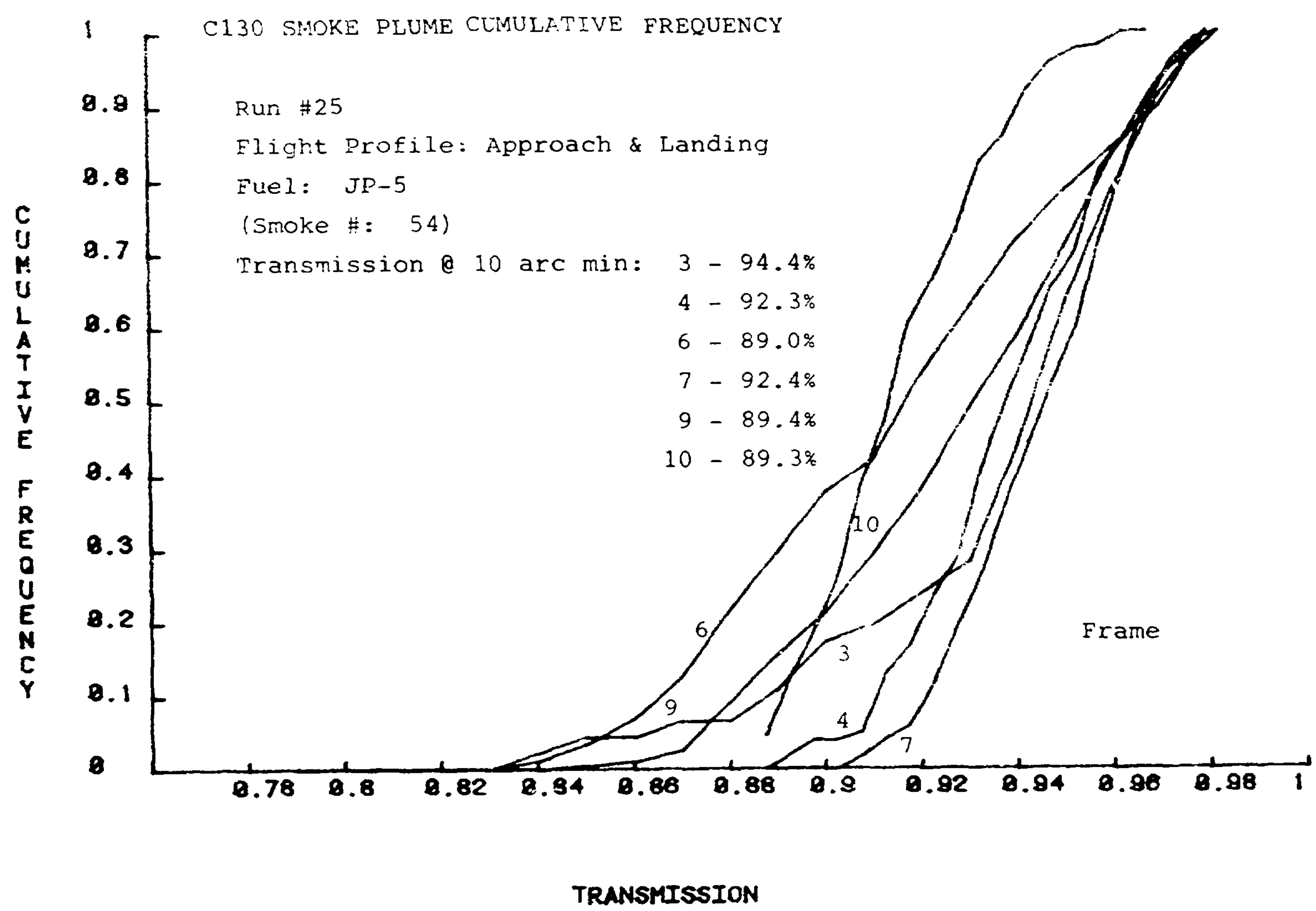

C130 SMOKE PLUME CUMULATIVE FREQUENCY
Run #23
Flight Profile: Approach & Landing
Fuel: JP-5
(Smoke #: 54)
Transmission @ 10 arc min:
2 - 94.2%
4 - 92.0%
5 - 86.8%
7 - 87.6%
9 - 82.3%
Frame
CUMULATIVE FREQUENCY
TRANSMISSION

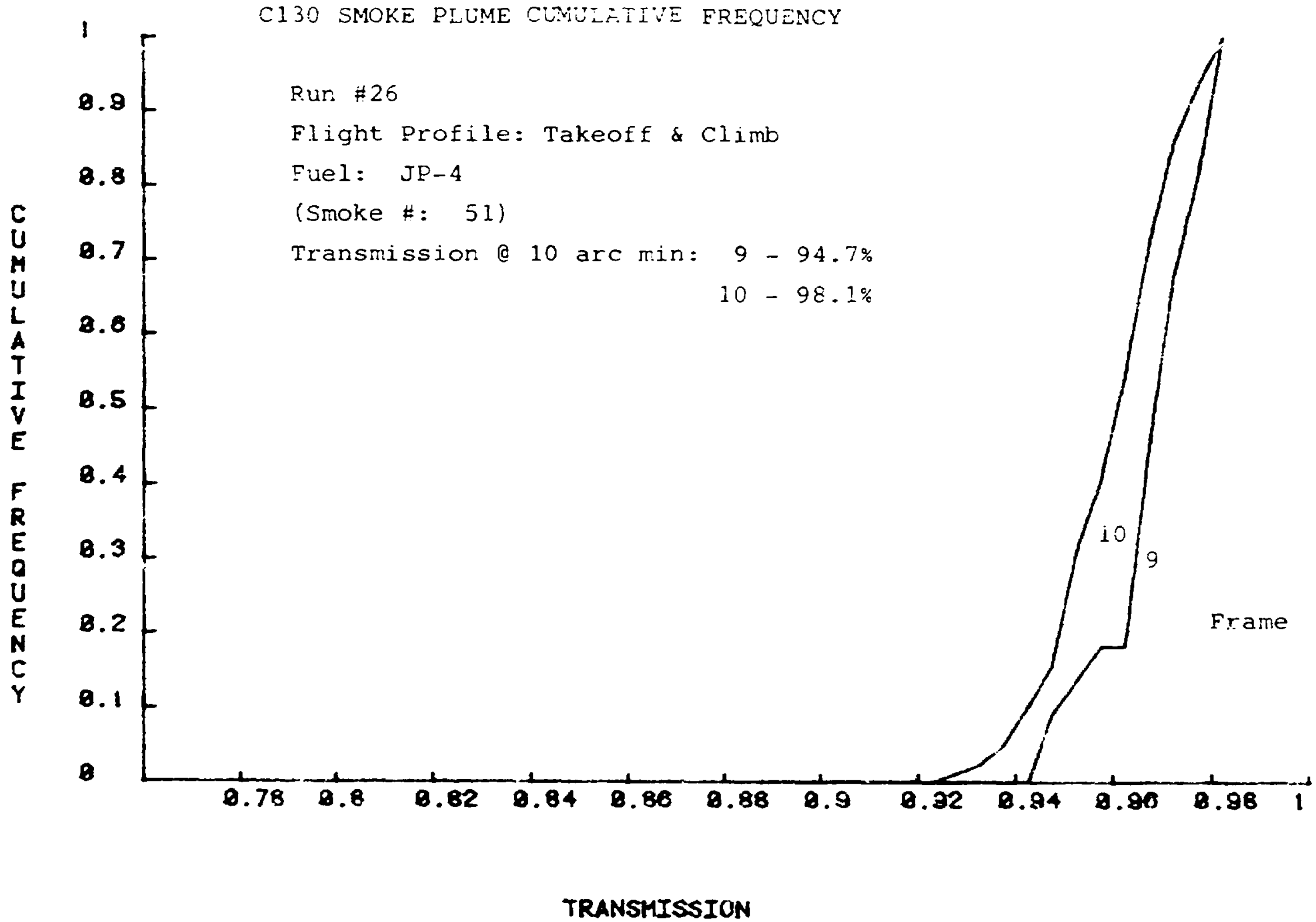
C130 SMOKE PLUME CUMULATIVE FREQUENCY

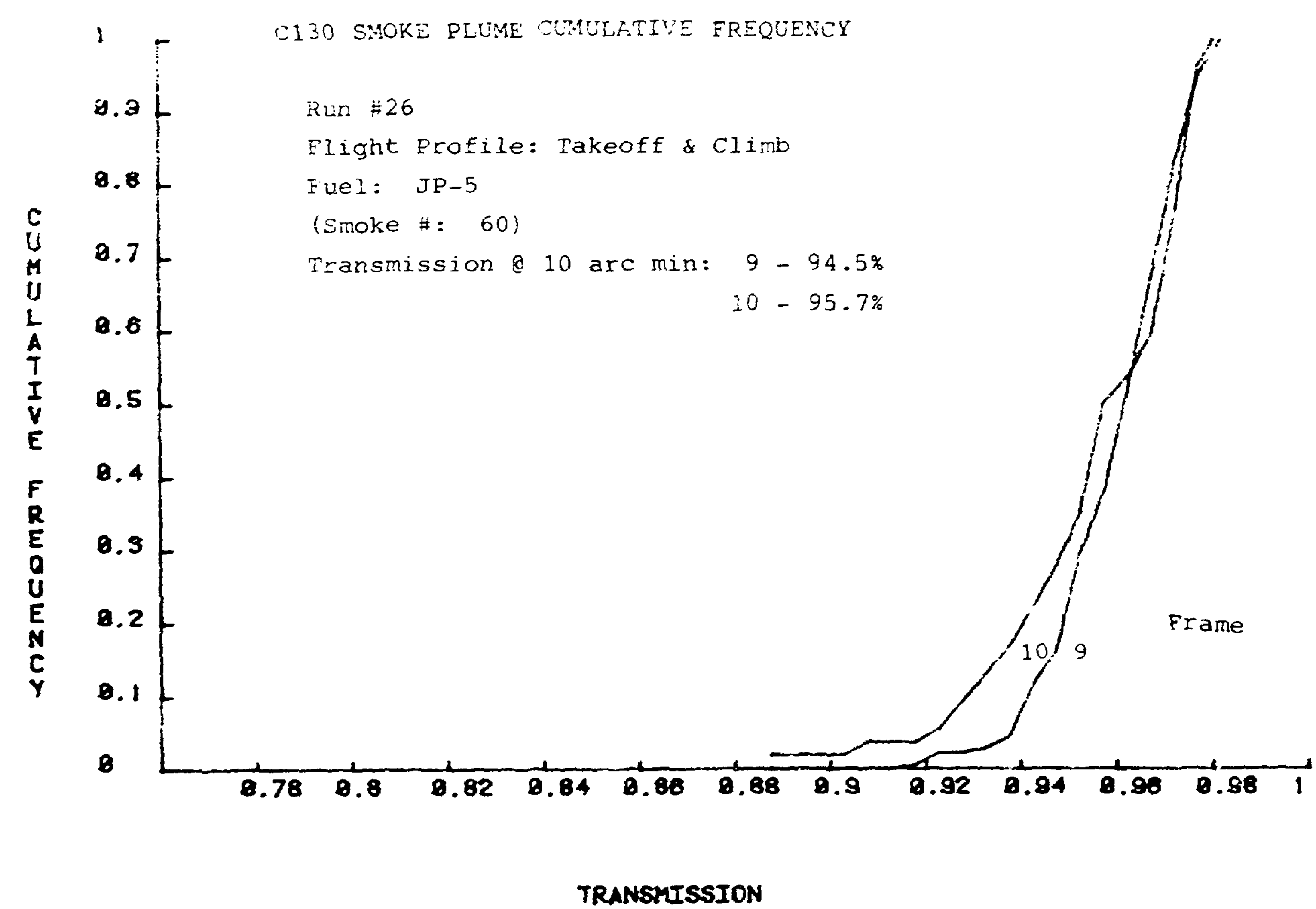


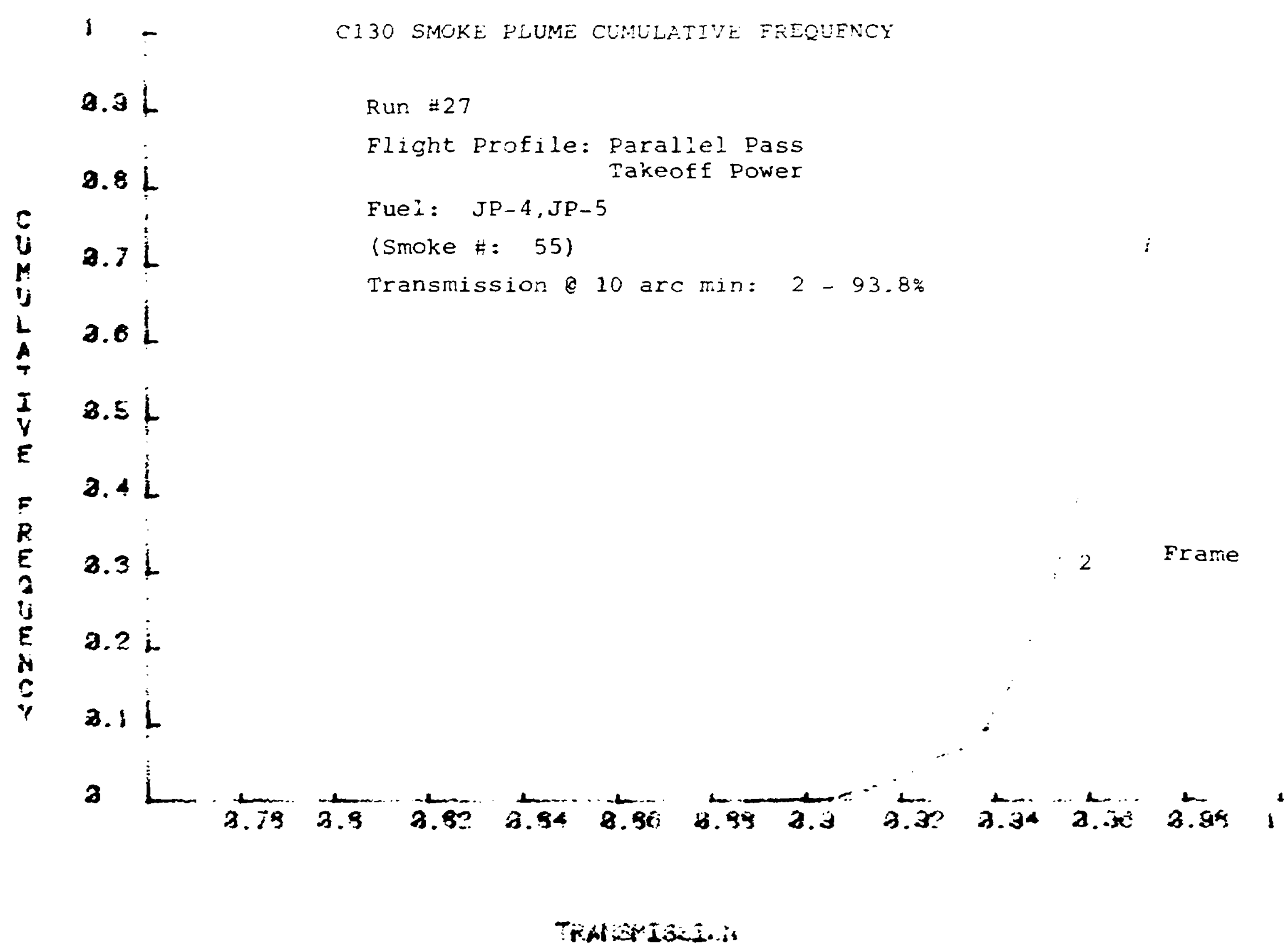


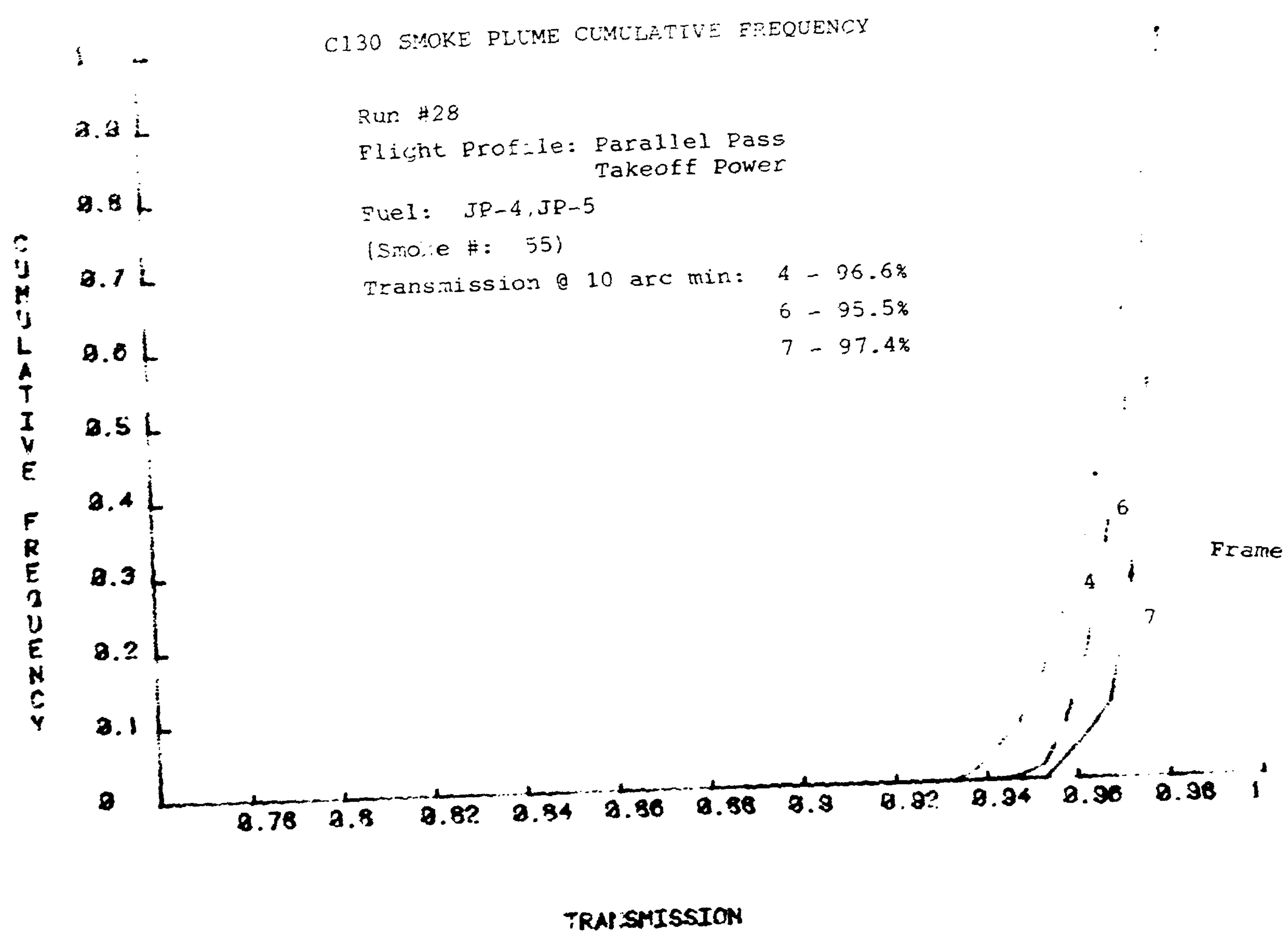
C130 SMOKE PLUME CUMULATIVE FREQUENCY
Run #25
Flight Profile: Approach & Landing
Fuel: JP-4
(Smoke #: 43)
Transmission @ 10 arc min: 3 - 97.3%
4 - 97.0%
6 - 98.2%
7 - 95.5%
9 - 95.0%
10 - 89.2%
Frame
CUMULATIVE FREQUENCY
TRANSMISSION
0.78 0.8 0.82 0.84 0.86 0.88 0.9 0.92 0.94 0.96 0.98 1
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1


C130 SMOKE PLUME CUMULATIVE FREQUENCY
Run #25
Flight Profile: Approach & Landing
Fuel: JP-5
(Smoke #: 54)
Transmission @ 10 arc min: 3 - 94.4%
4 - 92.3%
6 - 89.0%
7 - 92.4%
9 - 89.4%
10 - 89.3%
Frame
CUMULATIVE FREQUENCY
TRANSMISSION
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1


C130 SMOKE PLUME CUMULATIVE FREQUENCY
Run #26
Flight Profile: Takeoff & Climb
Fuel: JP-4
(Smoke #: 51)
Transmission @ 10 arc min: 9 - 94.7%
10 - 98.1%
CUMULATIVE FREQUENCY
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
10
9
Frame
TRANSMISSION


C130 SMOKE PLUME CUMULATIVE FREQUENCY
Run #26
Flight Profile: Takeoff & Climb
Fuel: JP-5
(Smoke #: 60)
Transmission @ 10 arc min: 9 - 94.5%
10 - 95.7%
CUMULATIVE FREQUENCY
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION
Frame
10
9

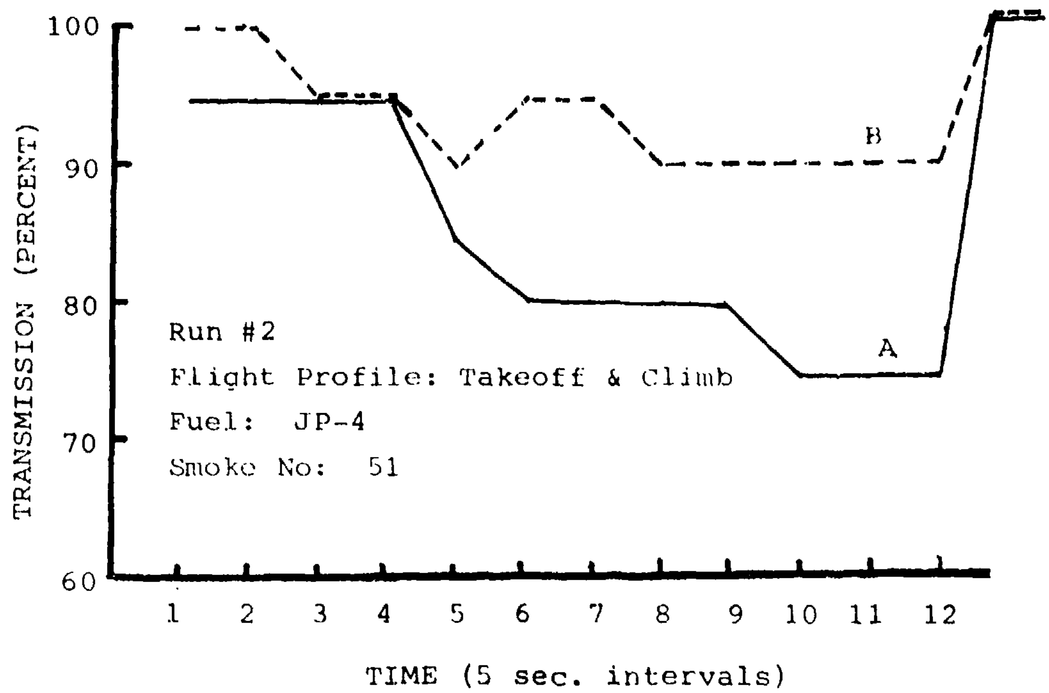

C130 SMOKE PLUME CUMULATIVE FREQUENCY
Run #27
Flight Profile: Parallel Pass
Takeoff Power
Fuel: JP-4,JP-5
(Smoke #: 55)
Transmission @ 10 arc min: 2 - 93.8%
2
Frame
CUMULATIVE FREQUENCY
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION

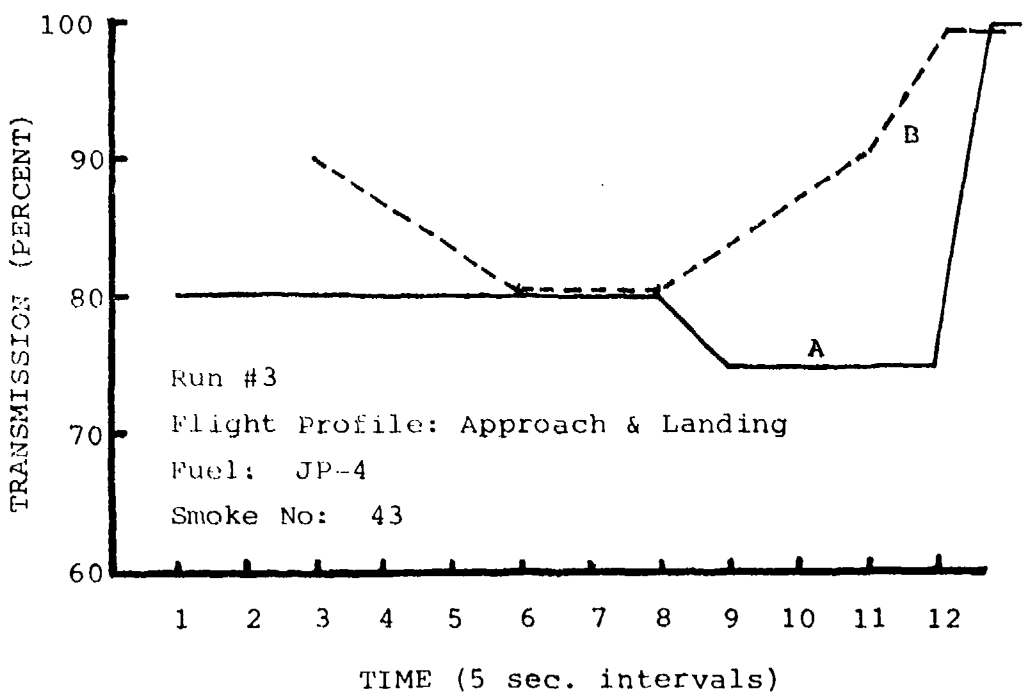

C130 SMOKE PLUME CUMULATIVE FREQUENCY
Run #28
Flight Profile: Parallel Pass
Takeoff Power
Fuel: JP-4,JP-5
(Smoke #: 55)
Transmission @ 10 arc min: 4 - 96.6%
6 - 95.5%
7 - 97.4%
Frame
4
6
7
CUMULATIVE FREQUENCY
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0.76
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
TRANSMISSION

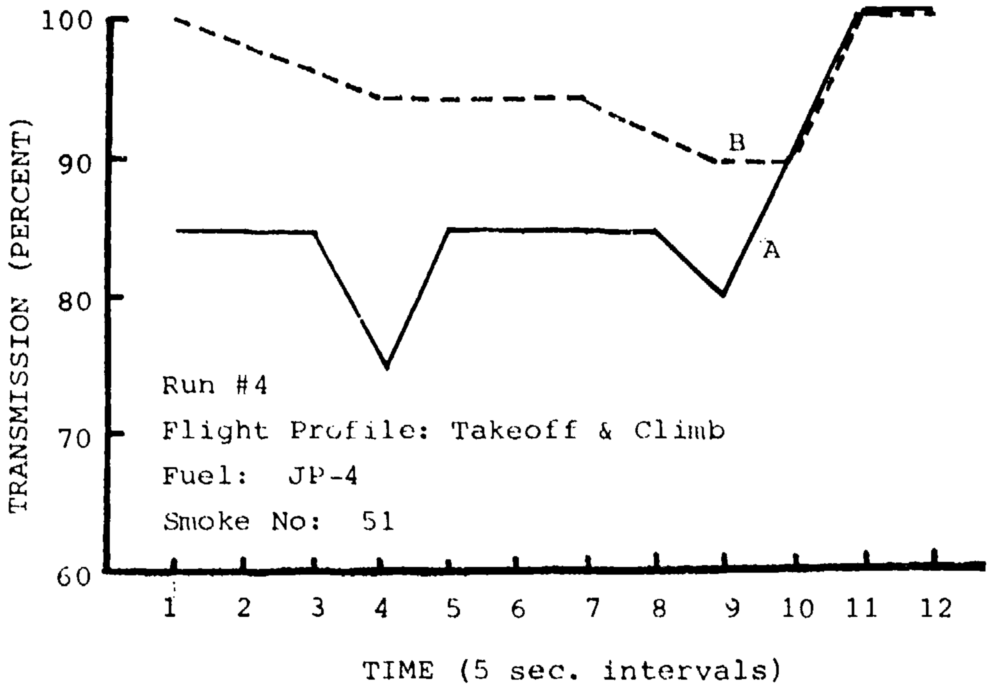
APPENDIX D

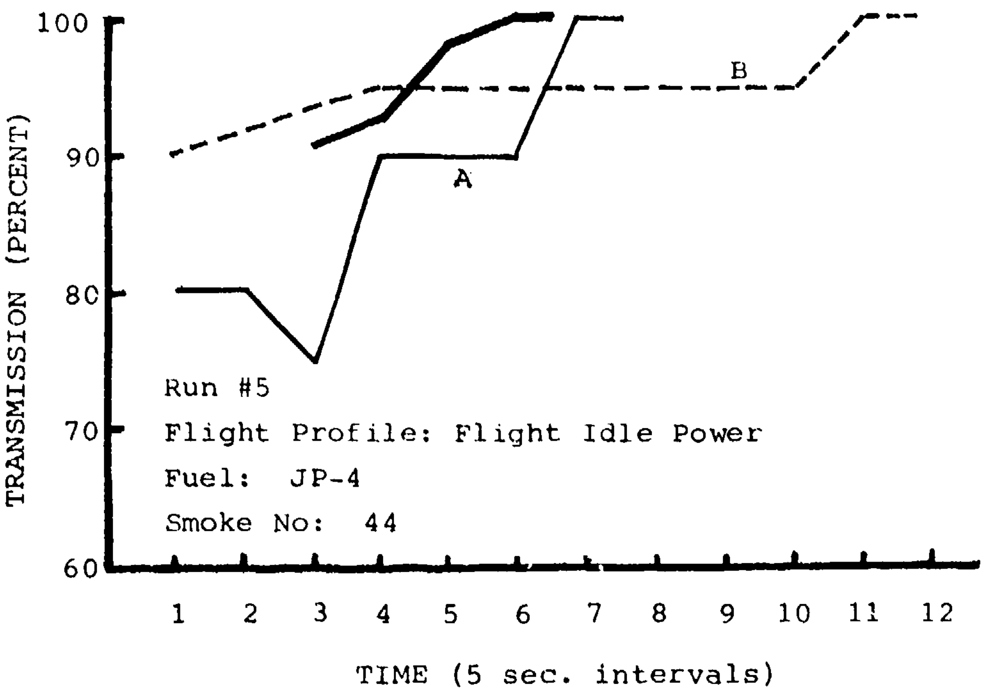
PHOTOGRAPHIC DATA VERSUS OBSERVER DATA

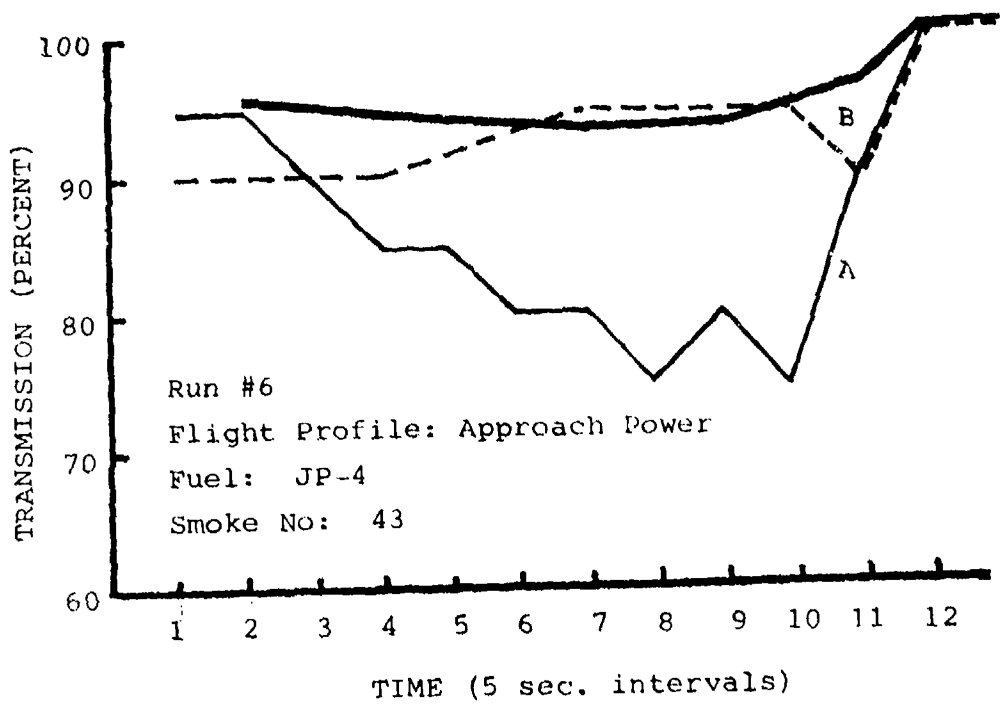
The photographic transmission data utilized for the smoke plume in these plots are approximately the average of a 5-to 15-arc minute angular size dark area.

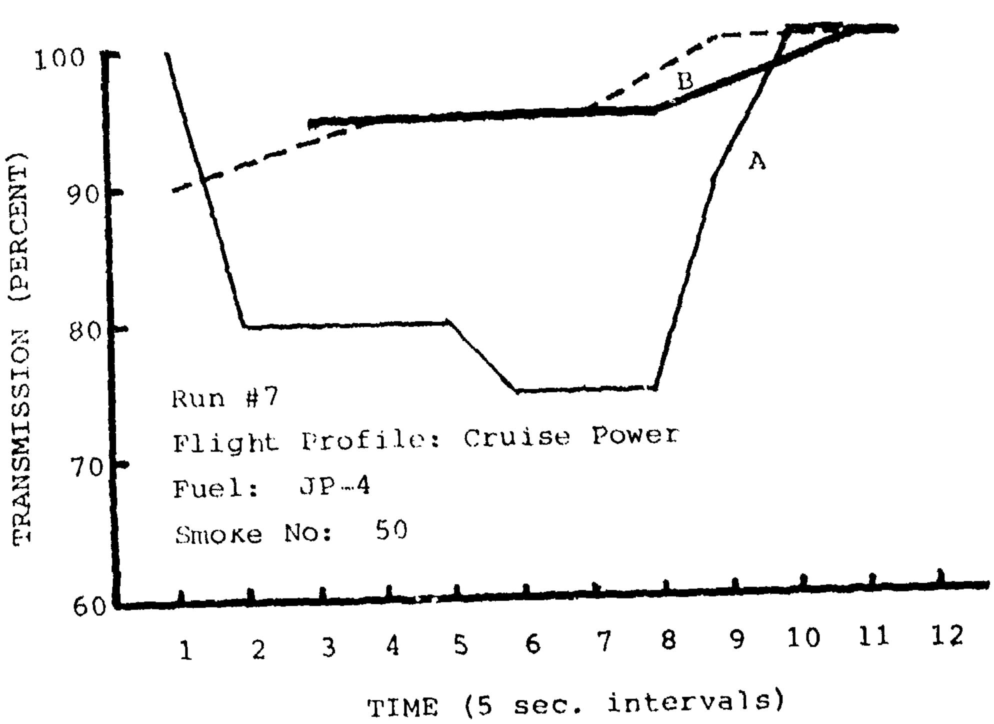

100
90
80
70
60
TRANSMISSION (PERCENT)
B
A
Run #2
Flight Profile: Takeoff & Climb
Fuel: JP-4
Smoke No: 51
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)

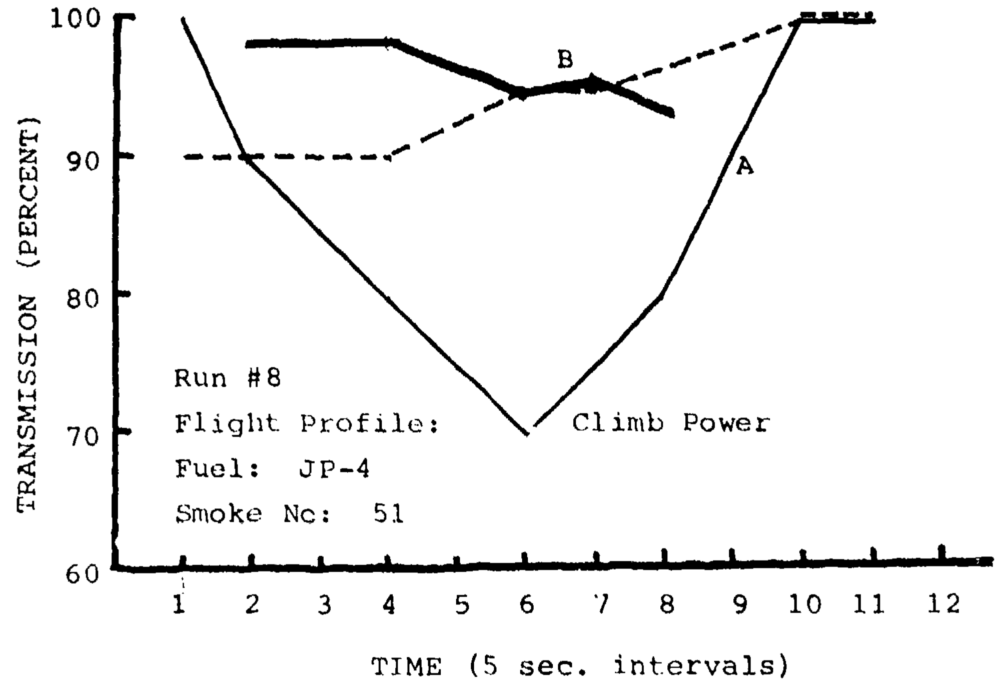

100
90
80
70
60
TRANSMISSION (PERCENT)
B
A
Run #3
Flight Profile: Approach & Landing
Fuel: JP-4
Smoke No: 43
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)

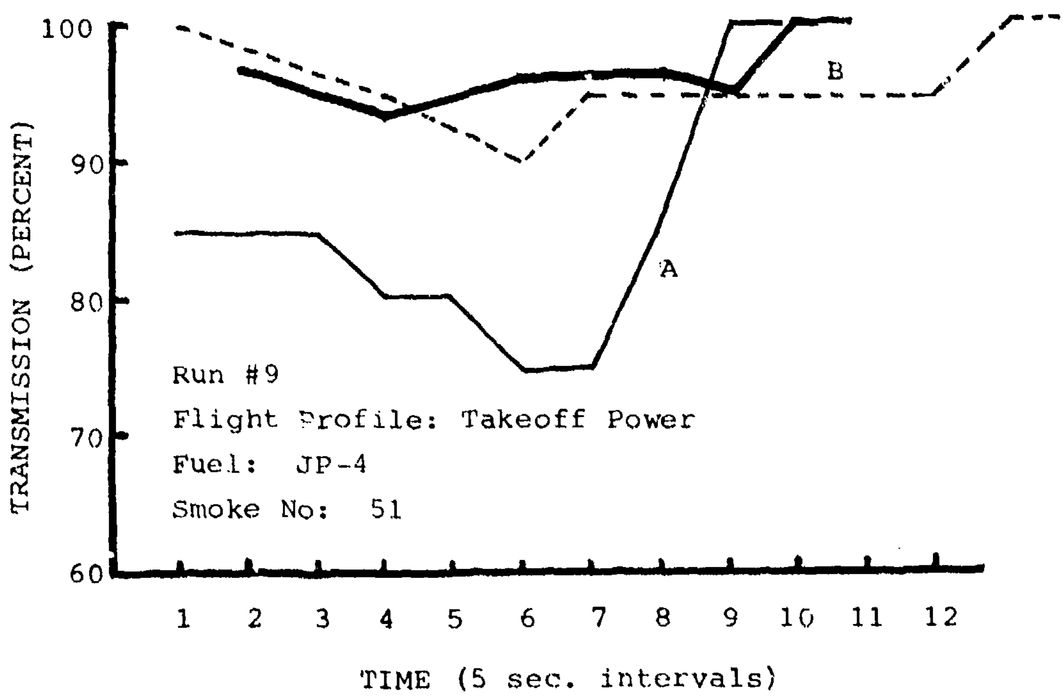

100
90
80
70
60
TRANSMISSION (PERCENT)
B
A
Run #4
Flight Profile: Takeoff & Climb
Fuel: JP-4
Smoke No: 51
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)

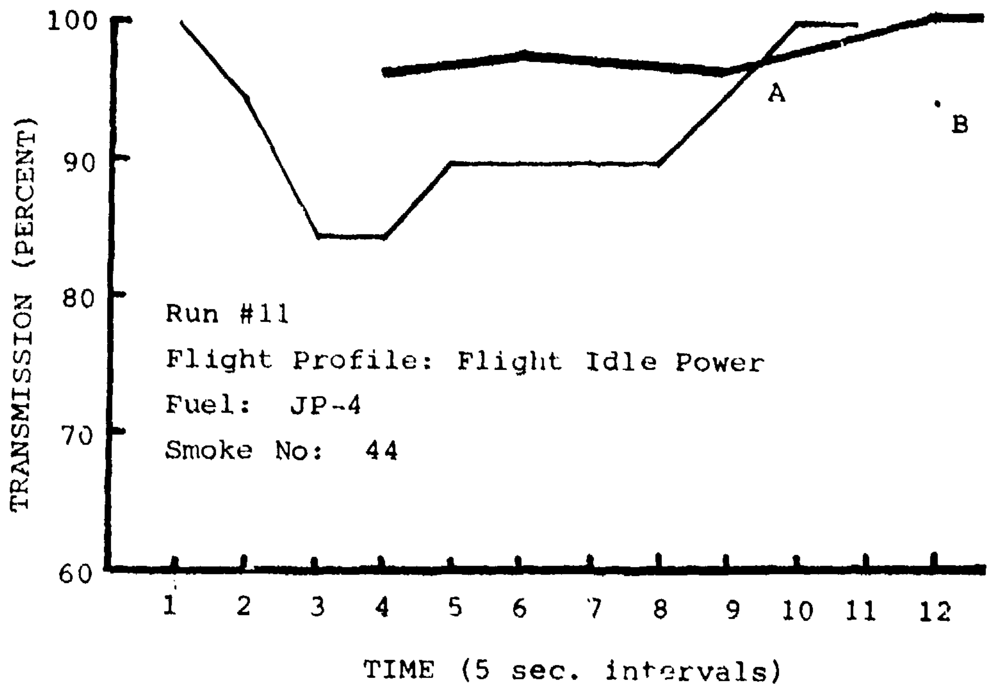

100
90
80
70
60
TRANSMISSION (PERCENT)
B
A
Run #5
Flight Profile: Flight Idle Power
Fuel: JP-4
Smoke No: 44
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)

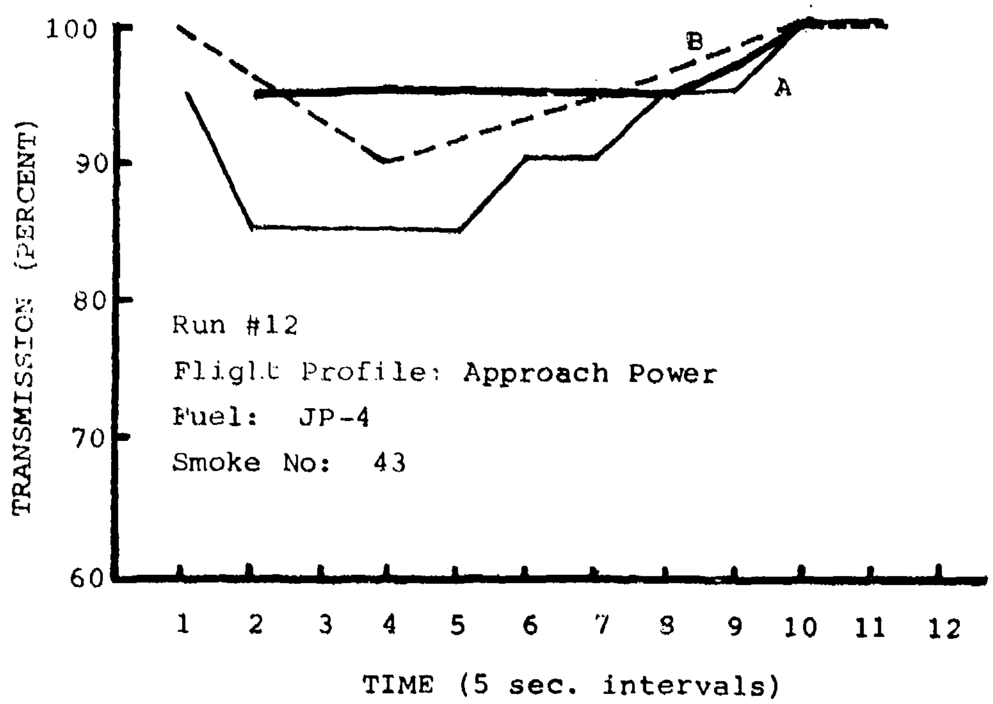

100
90
80
70
60
TRANSMISSION (PERCENT)
B
A
Run #6
Flight Profile: Approach Power
Fuel: JP-4
Smoke No: 43
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)

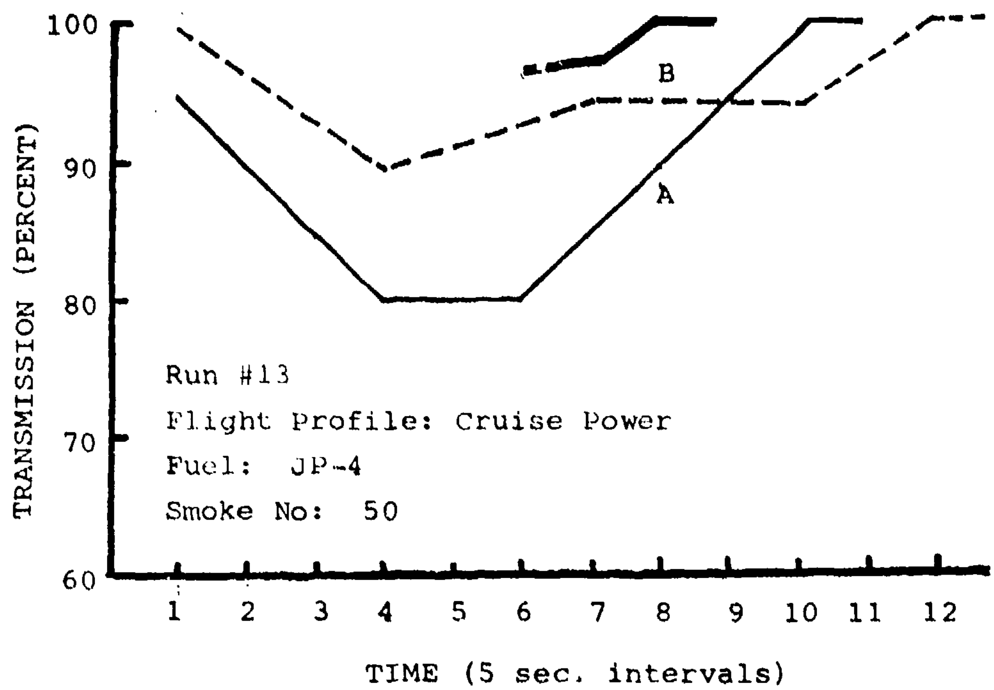

100
90
80
70
60
TRANSMISSION (PERCENT)
B
A
Run #7
Flight Profile: Cruise Power
Fuel: JP-4
Smoke No: 50
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)

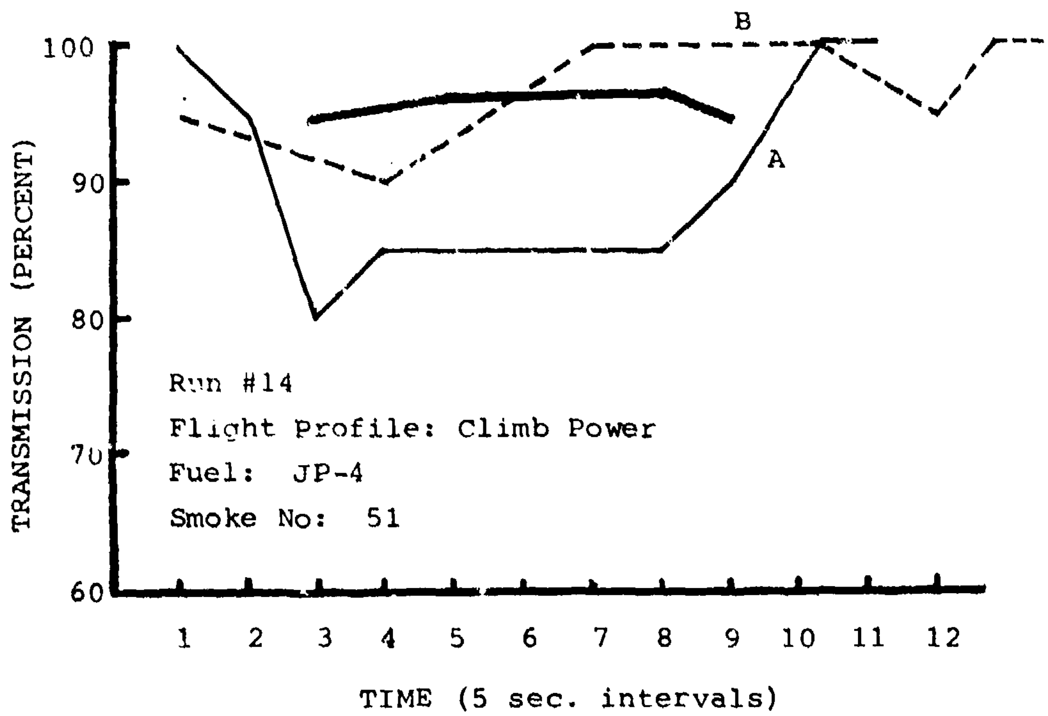

100
90
80
70
60
TRANSMISSION (PERCENT)
B
A
Run #8
Flight Profile: Climb Power
Fuel: JP-4
Smoke No: 51
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)

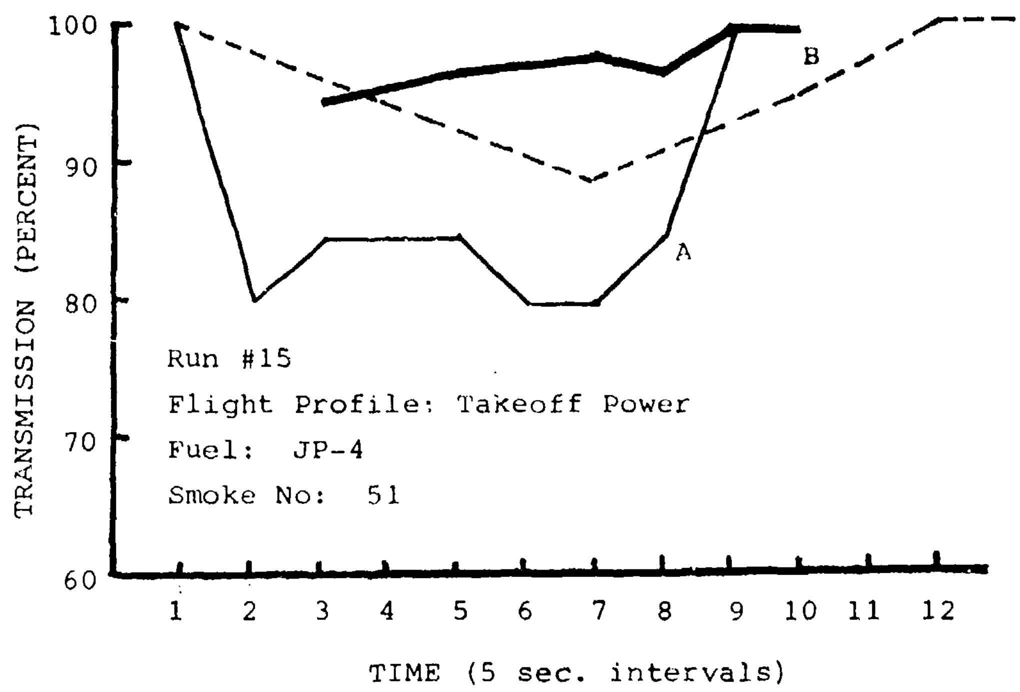

100
90
80
70
60
TRANSMISSION (PERCENT)
B
A
Run #9
Flight Profile: Takeoff Power
Fuel: JP-4
Smoke No: 51
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)

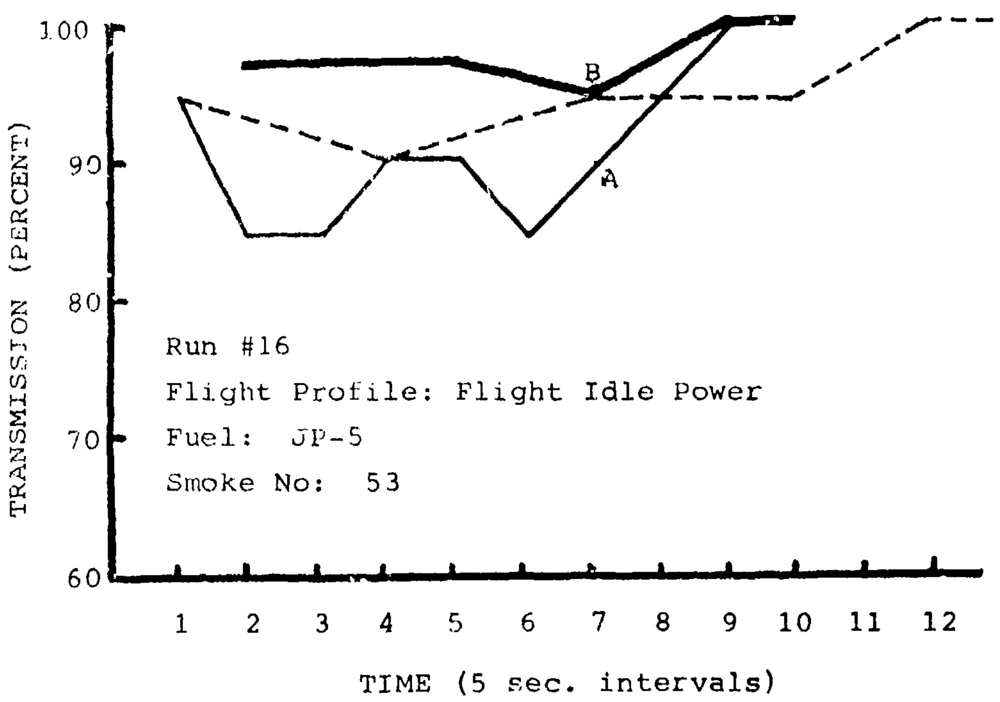

100
90
80
70
60
TRANSMISSION (PERCENT)
A
B
Run #11
Flight Profile: Flight Idle Power
Fuel: JP-4
Smoke No: 44
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)

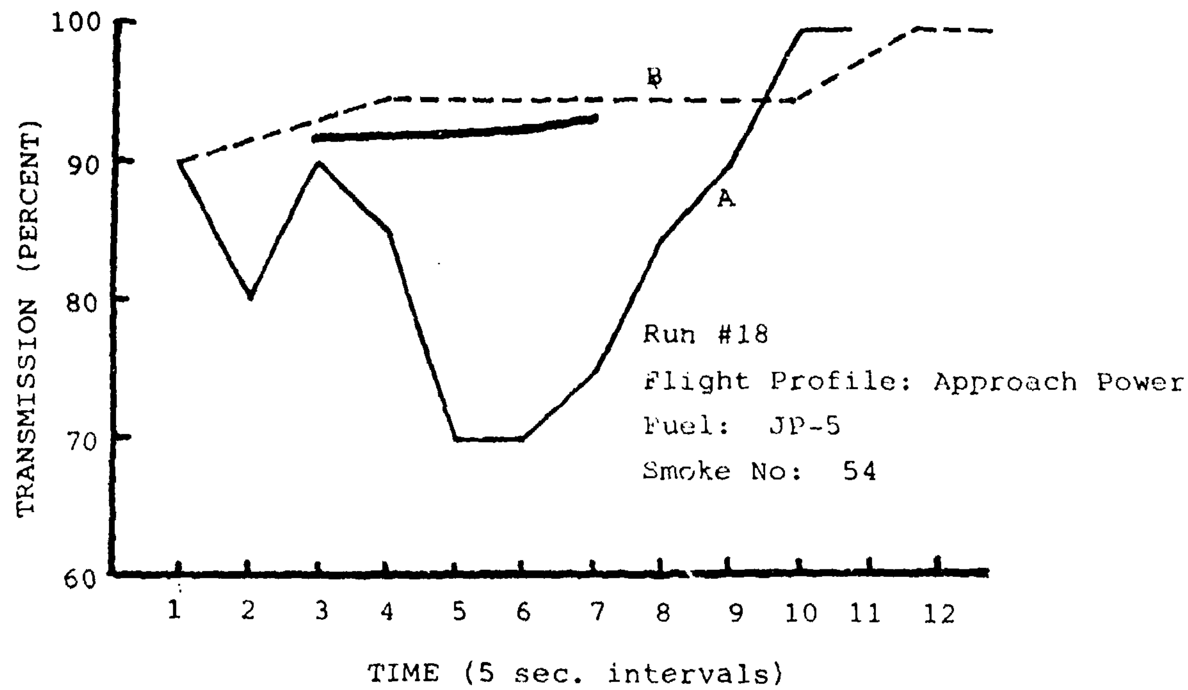

100
90
80
70
60
TRANSMISSION (PERCENT)
B
A
Run #12
Flight Profile: Approach Power
Fuel: JP-4
Smoke No: 43
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)

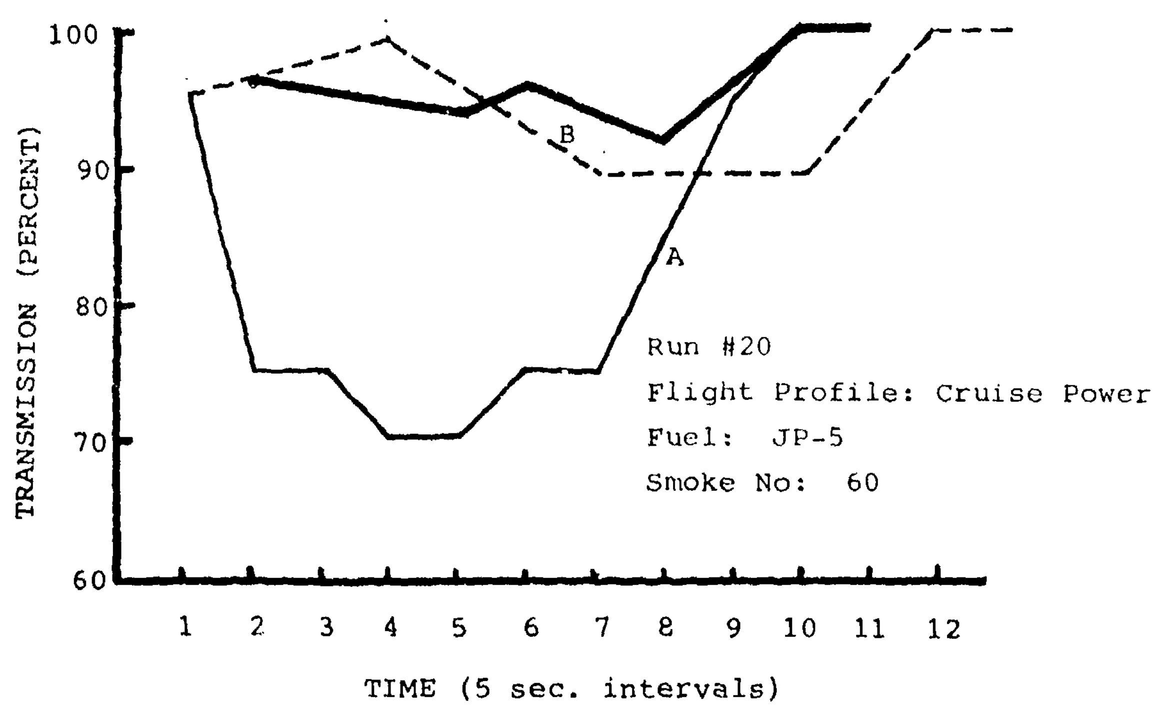

100
90
80
70
60
TRANSMISSION (PERCENT)
B
A
Run #13
Flight Profile: Cruise Power
Fuel: JP-4
Smoke No: 50
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)

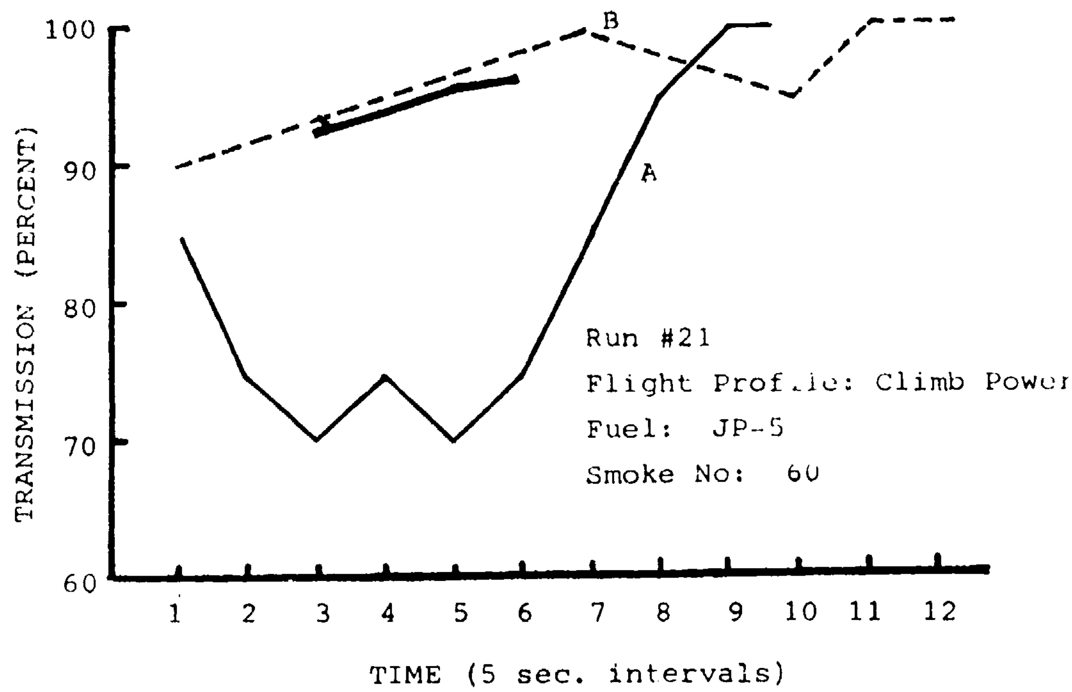

100
90
80
70
60
TRANSMISSION (PERCENT)
B
A
Run #14
Flight Profile: Climb Power
Fuel: JP-4
Smoke No: 51
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)


100
90
80
70
60
TRANSMISSION (PERCENT)
B
A
Run #15
Flight Profile: Takeoff Power
Fuel: JP-4
Smoke No: 51
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)

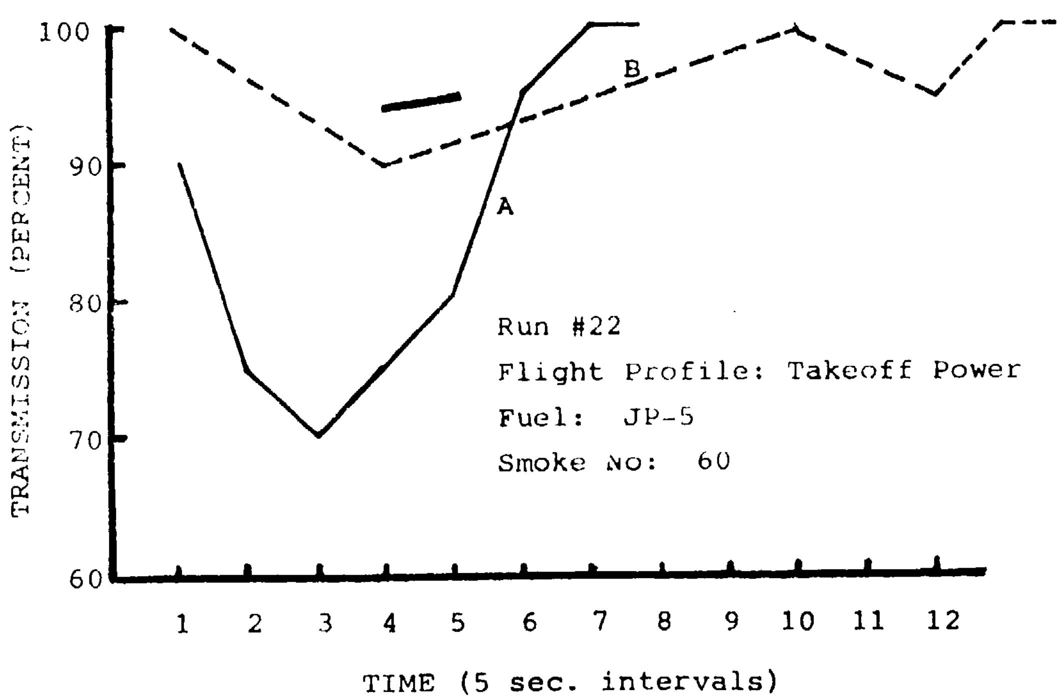

100
90
80
70
60
TRANSMISSION (PERCENT)
B
A
Run #16
Flight Profile: Flight Idle Power
Fuel: JP-5
Smoke No: 53
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)


100
90
80
70
60
TRANSMISSION (PERCENT)
B
A
Run #18
Flight Profile: Approach Power
Fuel: JP-5
Smoke No: 54
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)

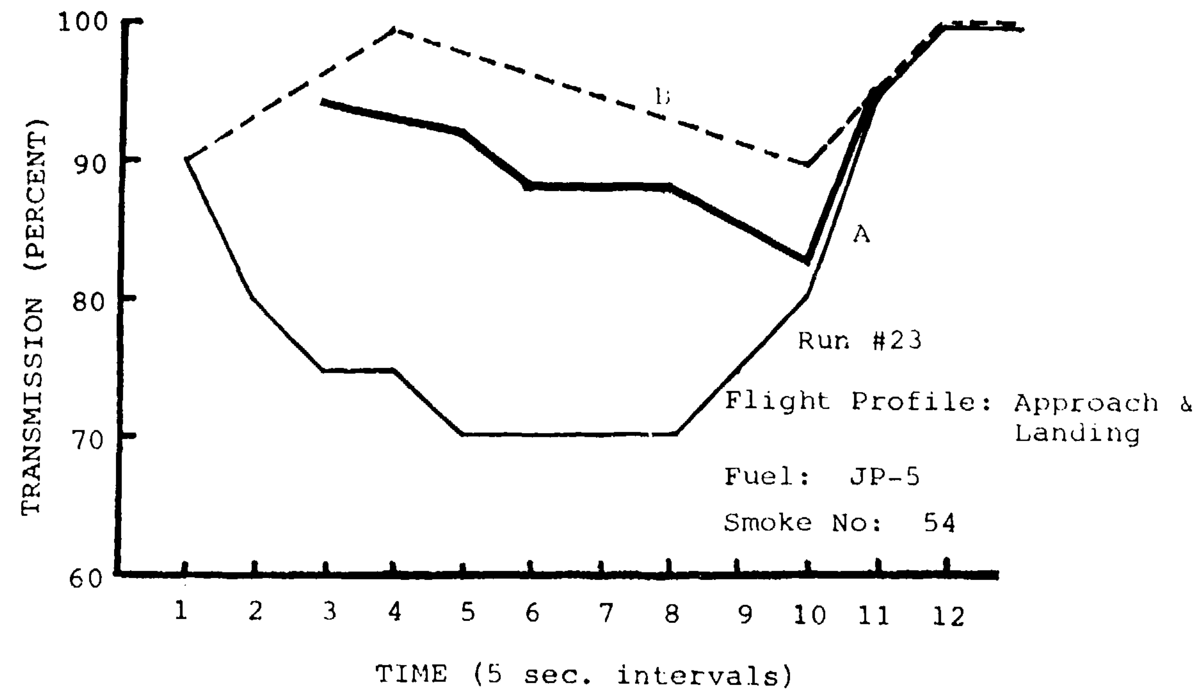

100
90
80
70
60
TRANSMISSION (PERCENT)
B
A
Run #20
Flight Profile: Cruise Power
Fuel: JP-5
Smoke No: 60
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)



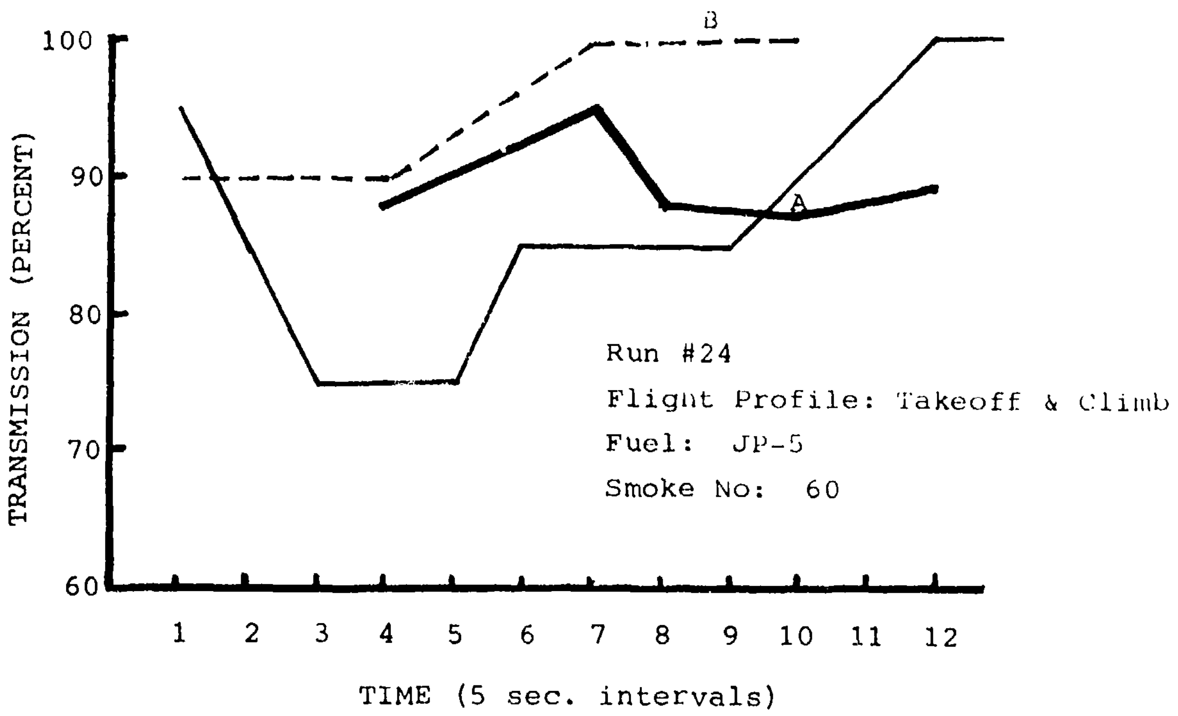
100
90
80
70
60
TRANSMISSION (PERCENT)
B
A
Run #21
Flight Prof.le: Climb Powe
Fuel: JP-5
Smoke No: 60
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)



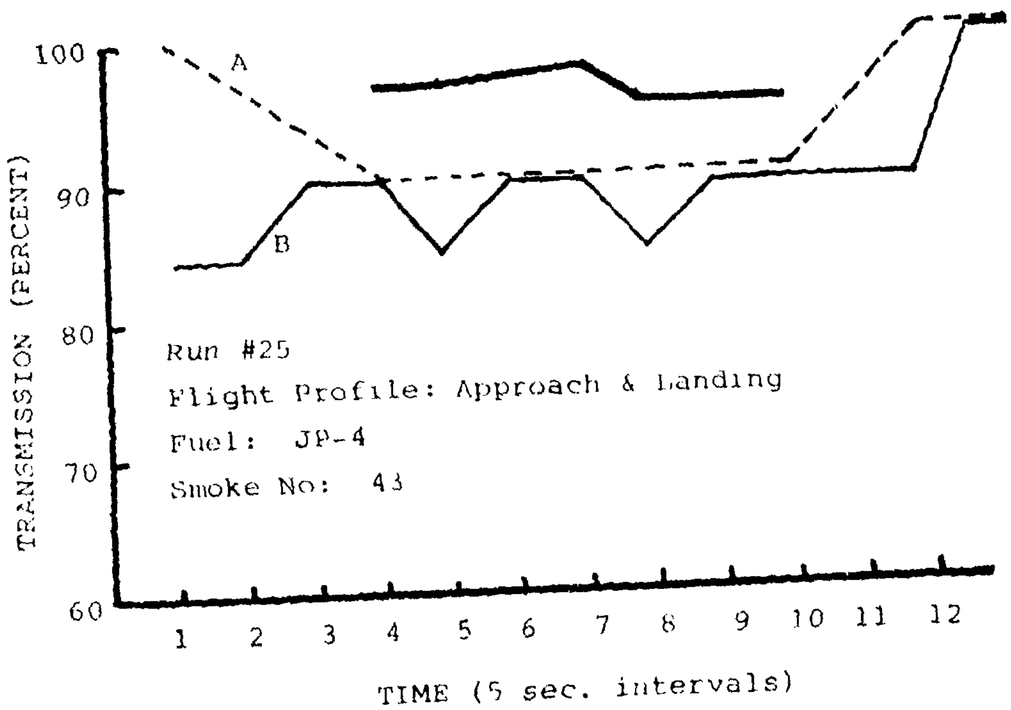
100
90
80
70
60
B
A
Run #22
Flight Profile: Takeoff Power
Fuel: JP-5
Smoke No: 60
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)

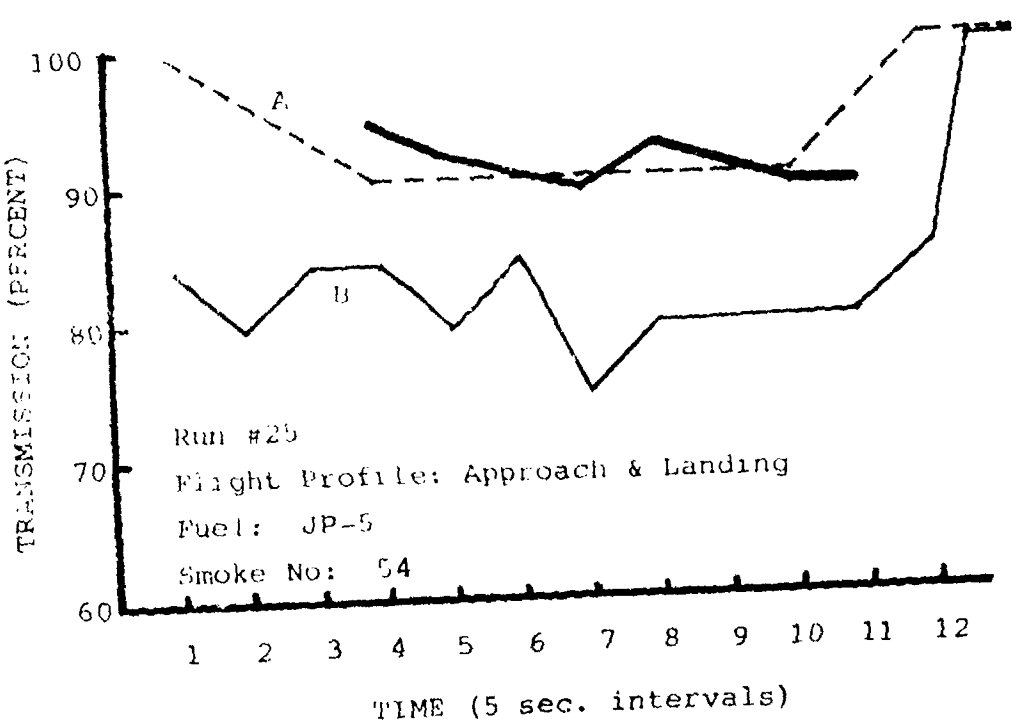


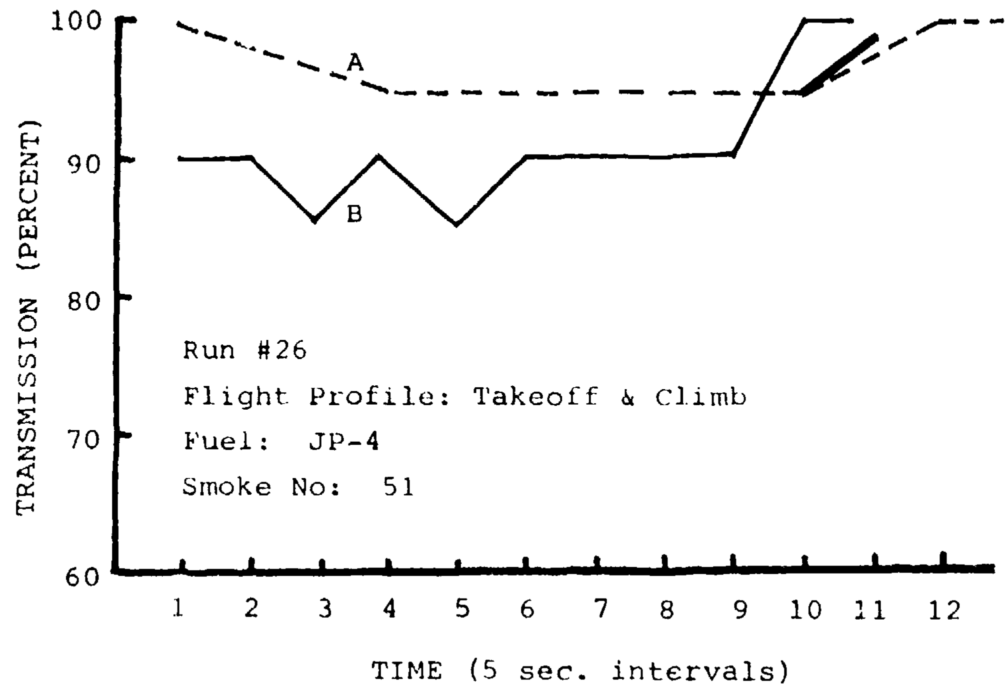
100
90
80
70
60
TRANSMISSION (PERCENT)
B
A
Run #23
Flight Profile: Approach & Landing
Fuel: JP-5
Smoke No: 54
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)



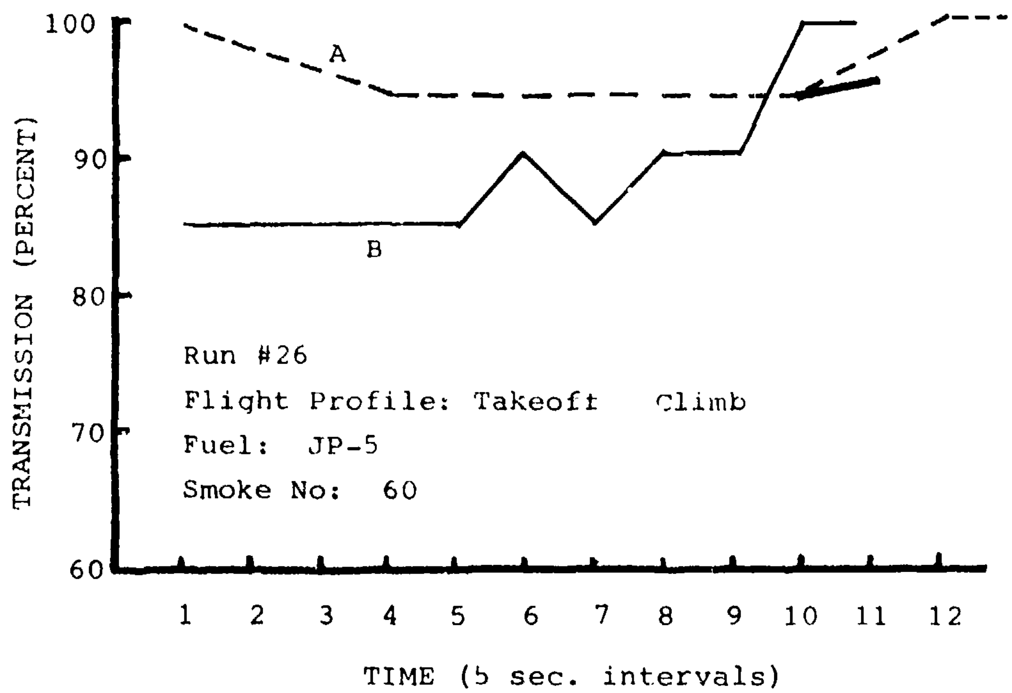
100
90
80
70
60
TRANSMISSION (PERCENT)
B
A
Run #24
Flight Profile: Takeoff & Climb
Fuel: JP-5
Smoke No: 60
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)


100
90
80
70
60
A
B
TRANSMISSION (PERCENT)
Run #25
Flight Profile: Approach & Landing
Fuel: JP-4
Smoke No: 43
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)

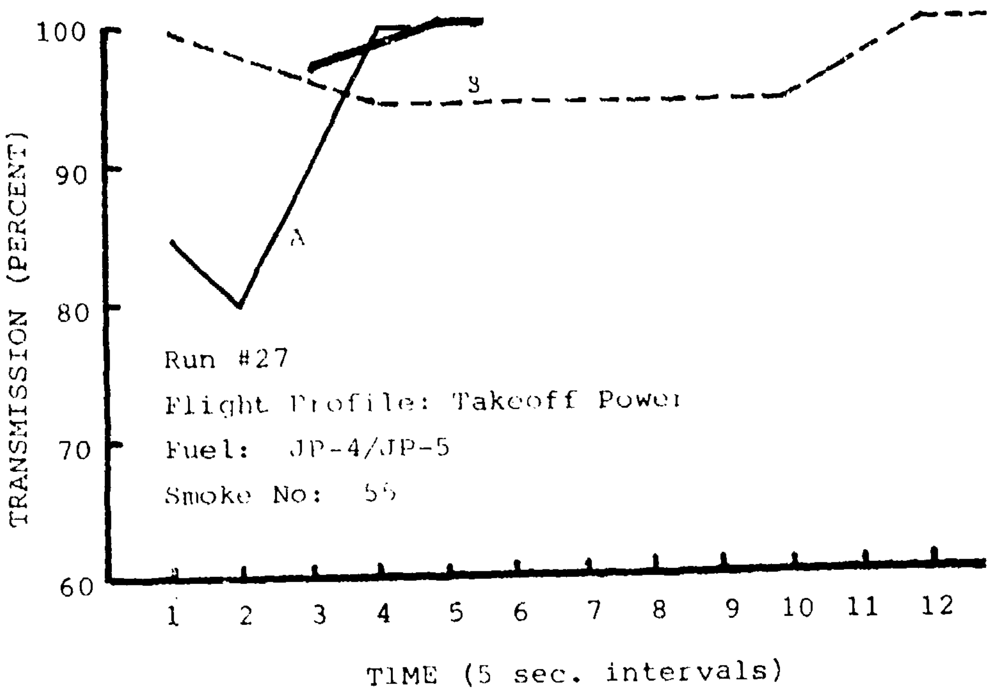

100
90
80
70
60
A
B
TRANSMISSION (PERCENT)
Run #25
Flight Profile: Approach & Landing
Fuel: JP-5
Smoke No: 54
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)

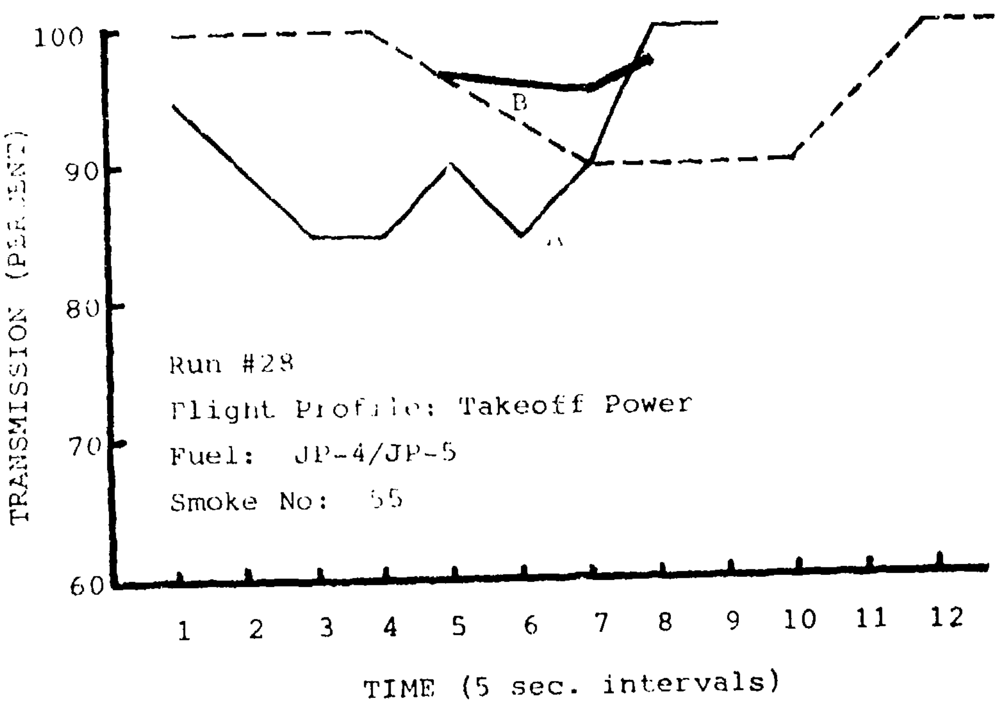


100
90
80
70
60
A
B
TRANSMISSION (PERCENT)
Run #26
Flight Profile: Takeoff & Climb
Fuel: JP-4
Smoke No: 51
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)



100
90
80
70
60
A
B
TRANSMISSION (PERCENT)
Run #26
Flight Profile: Takeoft Climb
Fuel: JP-5
Smoke No: 60
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)


100
90
80
70
60
TRANSMISSION (PERCENT)
B
A
Run #27
Flight Profile: Takeoff Power
Fuel: JP-4/JP-5
Smoke No: 55
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)


100
90
80
70
60
TRANSMISSION (PERCENT)
B
Run #28
Flight Profile: Takeoff Power
Fuel: JP-4/JP-5
Smoke No: 55
1 2 3 4 5 6 7 8 9 10 11 12
TIME (5 sec. intervals)