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B-1 AFT NACELLE FLOW VISUALIZATION STUDY

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SUMMARY

A 2-month program was conducted to perform engineering evaluation and design tasks to prepare for visualization and photography of the airflow along the aft portion of the B-1 nacelles and nozzles during flight test. Several methods of visualizing the flow were investigated and compared with respect to cost, impact of the device on the flow patterns, suitability for use in the flight environment, and operability throughout the flight. Data were based on a literature search and discussions with the test personnel. Tufts were selected as the flow visualization device in preference to several other devices studied. A tuft installation pattern has been prepared for the right-hand aft nacelle area of B-1 air vehicle No. 2.

Flight research programs to develop flow visualization devices other than tufts for use in future testing are recommended.

A design study was conducted to select a suitable motion picture camera, to select the camera location, and to prepare engineering drawings sufficient to permit installation of the camera. Ten locations on the air vehicle were evaluated before the selection of the location in the horizontal stabilizer actuator fairing. The considerations included cost, camera angle, available volume, environmental control, flutter impact, and interference with antennas or other instrumentation.

INTRODUCTION

Many valuable flight data are obtainable from current B-1 air vehicle testing that can be compared with wind tunnel, ground test, and analytical predictions to enhance the technology base for future transport aircraft. Flow separation along the aft portion of the B-1 nacelles and nozzles, as affected by wing interference flows, has been identified by NASA as a research area. Pressure fields on the nacelle are being measured under an Air Force Flight Dynamics Laboratory (AFFDL) program. Flow visualization would permit better interpretation of these pressure data, thus making the information on nacelle drag more useful.

This report presents the results of a study to:

1. Investigate methods of visualizing flow in the aft nacelle area of B-1 air vehicle No. 2 during flight test.

2. Select and describe appropriate flow visualization methods.

3. Recommend a suitable motion picture camera and select the camera location.

4. Conduct a design study to install the motion picture camera on the air vehicle to photograph the visualized flow.

The flow visualization techniques that were considered include the use of tufts, oil, and smoke. The design studies encompassed camera selection, camera location, wiring requirements, cooling requirements and methods, structural and flutter impact, and layout of the flow-visualization devices.

Follow-on effort to this program would include modifications to the B-1 engineering drawings, installation of camera and flow visualization devices, data acquisition during air vehicle flight test, analysis of the results including correlating the pictures with pressure changes over the nacelles, and writing the final research report. This program will not interfere with the B-1 program in any way.

Objectives

The objectives of this initial portion of the B-1 aft nacelle flow visualization program were to (1) conduct studies leading to selection of both a flow visualization technique and a camera, and (2) perform design studies to install the camera and the flow visualization devices.

Drawings in sufficient detail to enable complete installation of the camera system are furnished. Installation details of the flow visualization devices are also provided as part of this final report.

Background

The B-1 air vehicle exhibits a number of design and performance characteristics that make it an interesting subject for aeronautical research. Among these features is the nozzle-afterbody geometry resulting from the installation of advanced turbofan engines in two dual nacelles. The B-1 mission requirements necessitate large variations in the throat and exit areas of the nozzles. The nacelles must be faired into the afterbody mold lines of the nozzles in a manner that will optimize performance. Aerodynamic interactions between the nozzle and airframe result in a complex flow field which precludes a simple analysis. Experimental investigation is necessary both to support the analytical predictions of performance and to understand the flight test results. The resulting experimental data can then be used in research programs to improve the prediction methods.

There has been a continuing discrepancy between flight test results of aircraft performance and performance predictions that were based on wind tunnel test data. This discrepancy is significant at transonic conditions. Research programs are being conducted to improve the correlation procedures between the wind tunnel and flight test results that aim at yielding improved performance prediction techniques.

The B-1 is the research vehicle for the aircraft propulsion subsystem integration (APSI) program of the AFFDL. The objective of the APSI program is to generate inlet and nozzle flow field data by installation of pressure instrumentation on B-1 air vehicle No. 2 and wind tunnel models and to document the analysis of the reduced data. The opportunity is, therefore, presented to compare the detailed pressure information with the results of flow visualization on the B-1

The overall purpose of the B-1 aft nacelle flow visualization program is to accomplish the following during flight test:

1. Determination of flow direction

2. Identification of separated regions

3. Gain a better understanding of the pressure readings recorded during wind tunnel test and flight test

This program is a part of the continuing effort to help develop improved prediction techniques in propulsion aerodynamics.

FLOW VISUALIZATION STUDY

It is often desirable to study the characteristics of boundary layer airflow over aircraft structure. Such information is useful in analysis and interpretation of pressure measurements and can also be used to locate flow separations and identify configurations which cause undesired aerodynamic effects.

Flow visualization devices or techniques are quite commonly used during wind tunnel testing and, to a lesser degree, in flight testing. A wind tunnel installation provides advantages in use of flow visualization which are not available in flight testing. However, difficulties encountered in correlating wind tunnel and flight test results might be reduced if flow visualization was used during flight test.

Flow Visualization Requirements

It is not always possible to detect the presence of a separated flow from steady-state pressure distributions, especially if the flow separation is not steady. Figure 1 shows a typical nacelle/nozzle boattail, along with two curves of pressure coefficient as a function of distance along the boattail. It can be seen that there is an overexpansion at the shoulder and, if the flow remains attached, recompression occurs along the remainder of the surface. If the flow separates, the overexpansion at the shoulder is followed by recompression until separation occurs. After separation, there is negligible recompression. In cases similar to the figure, it is quite simple to detect separation; however, actual test data often do not clearly indicate the flow characteristics. It is believed that these interpretation problems are caused by unsteady flow which oscillates between attached and separated flow. Pressure measurements are normally time-averaged so they do not show these changes. Sampling pressure data at sufficient frequencies and rates to identify these fluctuations is virtually impossible in flight testing due to space and complexity considerations. A relatively simple flow visualization technique can provide the necessary information to allow interpretation of the pressure data.

The flow visualization technique used on the B-1 flight test program should have the following characteristics:

1. The visualization devices should not affect the nacelle flow, which could result in unrealistic pressure measurements or unrealistic behavior of the downstream visualization devices.

2. The visualization technique should be suitable for use throughout the flight.

3. The visualization devices should be capable of operation in the environment encountered during the flight test program.

In addition, the flow visualization program must not interfere with the B-1 air vehicle No. 2 schedule in any way.

Although it would be desirable to obtain flow visualization motion pictures of both upper and lower surfaces of the aft nacelle/nozzle of the B-1, it does not presently seem feasible to provide camera coverage of the lower surface. The area of interest for this program is shown on figure 2. It should be noted that this is also the area which uses flow visualization on the 0.06-scale model used for B-1 nozzle-afterbody performance verification and the APSI program. The aft nacelle/nozzle pressure measurements will be made on the left-hand nacelle; therefore, the right-hand nacelle will be used for flow visualization.

Candidate Techniques Survey

A short survey was conducted to identify candidate flow visualization techniques which would be suitable for use in the B-1 flight test program. This survey consisted of a literature search plus discussions with flight test and wind tunnel test personnel in both government and industry. Following is a discussion of the flow visualization survey.

Literature Search.- A literature search was conducted at the Rockwell Technical Information Center, the Defense Documentation Center, and the NASA Scientific and Technical Information Facility. A total of 684 bibliographies were compiled by the computer search. These bibliographies were reviewed, and 15 documents were ordered, of which seven were obtained. Prior to the initiation of the literature search, three reports dealing with flow visualization had been recommended by the NASA. These reports (ref 1, 2, and 3) involved flight testing where flow visualization devices were used; however, the primary subjects of the reports were not flow visualization. Of the seven other documents reviewed, only one (ref 4) deals with flight testing flow visualization. The other reports are concerned primarily with wind tunnel or laboratory flow visualization.

An interesting observation from reference 4 is that the authors feel that flow visualization is a very important qualitative method of understanding flow about air vehicles which has not been utilized and developed due to the modern trend toward sophisticated, expensive, and complex equipment. Another document (ref 5), although concerned with wind tunnel testing, discussed an interesting variation of the oil flow technique involving the use of paint carriers and overflowing fluids containing color producing chemicals. This technique permits erasure and reestablishment of flow patterns without shutdown in continuous-type wind tunnels. It appears that a technique of this type might be adaptable to aircraft flight testing. Erasable colors would overcome one of the major problems of oil flow in flight testing. This possibility will be discussed later in this report.

The literature search was not particularly successful and failed to produce any significant background data for flight test flow visualization. The abundance of wind tunnel flow visualization documentation indicates that this field has not been neglected. Unfortunately, most wind tunnel methods are not adaptable to flight testing as they use special lighting and conditions not available during flight test.

Discussions.- Discussions with flight test and wind tunnel personnel provided the bulk of the flow visualization information obtained in this study. It should be noted that there is knowledge about flight test flow visualization, but most of it is based on practical experience and the details are seldom reported. The following trade study is based on informal discussions with Rockwell and NASA personnel engaged in flight or wind tunnel testing.

Trade Study

Flow visualization devices/techniques considered for this program have been broken into two major groups:

Fluid Ejection.- The fluid ejection technique involves the ejection of a liquid or gas onto the surface or into the area to be studied. The liquid would normally adhere to the surface and move with the direction of flow. The viscosity and color of the liquid, usually oil, can be adjusted to provide the flow characteristics and visibility desired. This method, used extensively in wind tunnel testing, has several variations such as ejection of the fluid from a central tank through a system of tubes, painting the surface or spots of the fluid at specified locations. For flight testing, the spot or painting techniques are obviously not suitable. Either of the techniques requires that the surface be cleaned and new fluid applied for the next test condition. Quite often, special lighting and fluorescent oils are used for wind tunnel flow visualization. As mentioned earlier, reference 5 discussed the use of chemicals to erase previous flow patterns thus allowing operation in a continuous tunnel. No information on flight test use of this technique has been found.

The other fluid technique, which uses a gas such as smoke, has been employed in low-speed wind tunnels and, in some cases, for flight testing. Flight test use of smoke has usually been at low speeds or to investigate wing-tip vortices. The gas-smoke technique might be suitable for some conditions, but photography appears to be very difficult. In the case of the B-1 flight test program, with the camera located in the tail area, visibility would be extremely poor.

Fixed Devices.- Fixed flow visualization devices are defined as any device/indicator which is attached to the surface of the aircraft but is free to move, indicating flow characteristics. A fixed device might be a tuft or perhaps a vane. Generally, fixed flow indication devices can be expected to influence downstream flow to a greater extent than fluid indicators such as oil. Tufting has been used extensively for both wind tunnel and flight test work. Tufting materials cover a broad range from cotton yarn to fiberglass sleeving. Attachment methods range from tape to RTV, epoxy, or even mechanical fasteners. The tufting materials and attachment methods are dictated by the environment. The major advantages of tufting are low cost, ease of installation or relocation, and minimal impact on other systems. Vanes have been used with some success, generally in combination with pressure measurements.

Recommendations.- Table I lists the four candidate flow visualization techniques and the selection criteria. The candidates are listed in order of preference. Within the constraints of the B-1 manufacturing and flight test schedule, tufting has been selected for flow visualization in conjunction with a tail-mounted motion picture camera. The other candidate techniques with the exception of vanes would require extensive research and development prior to flight use. Although tufting has been selected for this program, fluid ejection seems to offer several advantages if it can be developed for flight test work.

It is suggested that NASA consider a separate research program to investigate the feasibility of a fluid ejection (oil or chemical flow) system for flight test flow visualization. It is expected that the program would include analysis, design, laboratory tests, wind tunnel tests, and, finally, flight tests. There appears to be a definite need for improved standardized flight test flow visualization techniques throughout the industry.

Tufting Installation

The tufts will be installed on the visible portion of the right-hand nacelle in locations corresponding to the pressure measurements on the left-hand nacelle. The tufts will be identified by the same numbers that are used for pressures, followed by the letter T. This identification method will aid in correlation of visualization and pressure data. Usually, in flight testing, the flow visualization devices and pressure measurements are on the same nacelle, and identical locations cannot be used. Figure 3 shows a view of the left-hand nacelle with the pressure measurement locations. Figure 4 shows the same view of the right-hand nacelle with the tuft locations. The extreme aft portions and bases of the nozzles will not be tufted. The tuft location coordinates are listed on table II.

NASA experience on the YF-12 test program indicates that fiberglass sleeving is well suited for high-temperature applications. The only extreme temperatures are encountered on the aft portion of the nozzle and interfairing. The fiberglass sleeving will be satisfactory at the maximum expected nozzle exterior temperature of 700° K (800° F). The nozzle tufting attachment or bonding method has been discussed with General Electric, and they will be asked to approve the

TABLE I.- FLOW VISUALIZATION EVALUATION

Technique	Prior use	Design features	Impact on aircraft systems	Advantages	Disadvantages	Comment
Fixed device (tufts).	Used extensively for both wind tunnel and flight test.	Bond tufts to surface.	Minimum	Low-cost installation. Flexibility. No aircraft modification required. Fixed point on aircraft. Sensitive to flow changes.	Rapid motion can cause poor visibility. Short life. Difficult analysis. Affects flow field.	Low cost, low risk, and installation flexibility. Most suitable for current flight test program. Relative rank - 1
Fixed device (vanes).	Limited flight test use as a mapping device. Used on nose booms to determine flow direction.	Mechanical device attached to aircraft skin.	Holes and fasteners in skin. Cumbersome if used as a mapping tool.	Longer life than tufts. Could be used in conjunction with pressure measurements.	Higher cost than tufts. Less flexible and more complex than tufts. Affects flow field.	Offers no significant advantage over tufting. Relative rank - 2

TABLE I.- FLOW VISUALIZATION EVALUATION - Continued

Technique	Prior use	Design features	Impact on aircraft systems	Advantages	Disadvantages	Comment
				Can yield flow direction quantitatively, such as angle of attack.	Do not yield three-dimensional flow visualization as tufts do.	
Fluid ejection (colored oil).	Used for wind tunnel and laboratory tests. No known flight test.	Would add plumbing, orifices, ejection mechanism, and controls. Could result in substantial design modifications.	Aircraft modification to install. Possible damage to other instrumentation. Adds ejection mechanism and control system.	Minimum effect on flow field. Good definition of flow field with increased confidence in interpretation.	Aircraft modification required. High cost technique required. Not developed for flight test; not compatible with B-1 schedule. Fluid freedom makes location difficult.	This technique appears to offer many advantages, but development time and associated risk makes it unsuitable for B-1 program. Relative rank - 3

TABLE I.- FLOW VISUALIZATION EVALUATION - Concluded

Technique	Prior use	Design features	Impact on aircraft systems	Advantages	Disadvantages	Comment
					Once installed, minor relocation would be difficult.	
Fluid ejection (smoke).	Used for low-speed wind tunnel and flight test.	Would require flow-generation system and associated controls.	Aircraft modification to install.	Minimum effect on flow field not constrained.	Aircraft modification required. Rapid dissipation and loss of visibility. Camera location probably not suitable for 3 dimensional body at transonic conditions.	Not considered suitable for this program. Relative rank - 4

TABLE II.- TUFT LOCATIONS

Tuft No.	Location	Coordinates*			
		Y_N		X_N	
87T	Interfairing	1047.2	(412.3)	-35.6	(-14.0)
88T		1066.0	(419.7)	-21.1	(-8.3)
89T		1088.4	(428.5)	-12.7	(-5.0)
92T		1088.4	(428.5)	12.7	(5.0)
93T		1066.0	(419.7)	21.1	(8.3)
94T		1047.2	(412.3)	35.6	(14.0)
95T		1079.5	(425.0)	-3.8	(-1.5)
96T		1106.7	(435.7)		
97T		1118.4	(440.3)		
98T		1122.7	(442.0)		
99T		1126.5	(443.5)		
100T	Interfairing	1130.3	(445.0)	-3.8	(-1.5)
139T	Outboard nacelle	948.1	(373.25)	113.0	(44.5)
140T	Outboard nacelle	977.1	(384.7)	129.5	(51.0)
141T	Fuselage	848.4	(334.0)	-152.9	(-60.2)
142T		924.6	(364.0)		
143T		983.0	(387.0)		
144T		1020.6	(401.8)		
145T		1066.8	(420.0)	-152.9	(-60.2)
151T		793.2	(312.3)	-131.3	(-51.7)
152T		847.6	(333.7)		
153T		881.4	(347.0)		
154T		931.4	(366.7)		
155T		968.5	(381.3)		
156T		990.6	(390.0)		
157T	Fuselage	1016.0	(400.0)	-131.3	(-51.7)

TABLE II.- TUFT LOCATIONS - Continued

Tuft No.	Location	Coordinates*			
		Y_N		X_N	
158T	Fuselage	1022.3	(402.5)	-131.3	(-51.7)
164T		793.0	(312.2)	-99.8	(-39.3)
165T		830.6	(327.0)		
166T		858.5	(338.0)		
167T		944.9	(372.0)	-99.8	(-39.3)
168T	Fuselage	980.3	(385.96)	-96.5	(-38.0)
169T	Fixed fairing	987.4	(388.75)	-86.4	(-34.0)
170T		998.2	(383.0)	-94.5	(-37.2)
171T		953.1	(375.25)	-89.4	(-35.2)
172T		982.9	(386.96)	-81.3	(-32.0)
173T		998.2	(393.0)	-80.3	(-31.6)
174T		967.1	(380.76)	-61.0	(-24.0)
175T		987.4	(388.75)	-68.6	(-27.0)
176T		998.2	(393.0)	-66.5	(-26.2)
177T		802.6	(136.0)	-66.0	(-26.0)
178T		835.7	(329.0)	-66.0	(-26.0)
179T		936.0	(368.5)	-59.7	(-23.5)
180T		795.5	(313.2)	-32.5	(-12.8)
181T		851.4	(335.2)		(-12.8)
182T		903.7	(355.8)		(-12.8)
183T		949.5	(373.8)	-32.5	(-12.8)
184T		786.9	(309.8)	0	0
185T		851.4	(335.2)	0	0
186T		949.5	(373.8)	0	0
187T	Fixed fairing	756.9	(298.0)	43.9	(17.3)

TABLE II.- TUFT LOCATIONS - Continued

Tuft No.	Location	Coordinates*			
		Y_N		X_N	
188T	Fixed fairing	810.3	(319.0)	40.1	(15.8)
189T	Underwing fairing		(350.0)		(11.0)
190T			(368.0)		(9.0)
191T			(298.0)		(25.1)
192T			(319.5)		(24.8)
193T			(350.3)		(20.0)
194T	Underwing fairing		(368.5)		(18.0)
		Y_N		X	
48T	Nozzle-engine No. 3	1109.0	(436.6)	2.36	(0.93)
200T				℄ Seal	
53T				2.36	(0.93)
201T				℄ Seal	
52T				2.36	(0.93)
202T				℄ Seal	
59T		1109.0	(436.6)	2.36	(0.93)
54T		1093.7	(430.6)	4.90	(1.93)
203T				℄ Seal	
61T				4.90	(1.93)
204T				℄ Seal	
60T				4.90	(1.93)
205T				℄ Seal	
67T		1093.7	(430.6)	4.90	(1.93)
62T		1070.1	(421.3)	7.44	(2.93)
206T	Nozzle-engine No. 3	1070.1	(421.3)	℄ Seal	

TABLE II.- TUFT LOCATIONS (Continued

Tuft No.	Location	Coordinates*			
		Y_N		X	
69T	Nozzle-engine No. 3	1070.1	(421.3)	7.44	(2.93)
207T		1070.1	(421.3)	℄ Seal	
68T		1070.1	(421.3)	7.44	(2.93)
208T		1070.1	(421.3)	℄ Seal	
75T		1070.1	(421.3)	7.44	(2.93)
70T		1030.5	(405.7)	11.38	(4.48)
209T				℄ Seal	
210T				11.38	(4.48)
211T				℄ Seal	
76T				11.38	(4.48)
212T	Nozzle-engine No. 3	1030.5	(405.7)	℄ Seal	
15T	Nozzle-engine No. 4	1109.0	(436.6)	2.36	(0.93)
213T				℄ Seal	
14T				2.36	(0.93)
214T				℄ Seal	
13T				2.36	(0.93)
215T				℄ Seal	
20T		1109.0	(436.6)	2.36	(0.93)
23T		1093.7	(430.6)	4.90	(1.93)
216T				℄ Seal	
22T				4.90	(1.93)
217T				℄ Seal	
21T				4.90	(1.93)
218T				℄ Seal	
28T	Nozzle-engine No. 4	1093.7	(430.6)	4.90	(1.93)

TABLE II.- TUFT LOCATIONS - Continued

Tuft No.	Location	Coordinates*			
		Y_N		X	
31T	Nozzle-engine No. 4	1070.1	(421.3)	7.44	(2.93)
219T				℄ Seal	
30T				7.44	(2.93)
220T				℄ Seal	
29T				7.44	(2.93)
221T				℄ Seal	
36T		1070.1	(421.3)	7.44	(2.93)
222T		1030.5	(405.7)	℄ Seal	
37T				11.38	(4.48)
223T				℄ Seal	
224T	Nozzle-engine No. 4	1030.5	(405.7)	11.38	(4.48)

*Distances are in centimeters (inches), and nozzle locations have Y_N distances with nozzle in closed position; Nozzle hinge line = Y_N 1012.4 (398.6); X = distance from nozzle flap centerline.

X_N = Distance from nacelle centerline outboard +, inboard -. (See figure 3.)

method selected. The interfairing will not exceed 700° K (800° F), and tufting will be attached by either suitable bonding or mechanical devices.

No thermal problems are anticipated on the other areas to be tufted, but for consistency, the fiberglass will be used at all locations. The initial installation will use white tufts approximately 10 cm (4 inches) long and 5/8 cm (1/4 inch) in diameter. It should be noted that tuft locations, sizes, materials, and attachment methods can be modified as needed during the flight test program.

CAMERA AND ACCESSORY SELECTION

An assembly sketch of the optical equipment is shown on figure 5.

Camera

The Milliken DBM-44, 16 mm, high-speed motion picture camera, with intermittent film transport and positive registration pin, has been selected for use in the flow visualization program. This camera is described in detail in reference 6. This camera is similar to and electrically identical to equipment already designated for use on the B-1 air vehicle(s). The DBM-44 was selected because of its compatibility with the other B-1 flight test cameras, thus aiding in ease of maintenance and availability of spares.

Automatic Exposure Control

Automatic exposure control (AEC) is considered essential to provide control over the continuously changing light conditions of flight test operations. The Photomatrix Apex-B AEC was chosen for this program. This device is described in reference 7.

Lens

An integral part of the Apex-B AEC is the lens. Procurement of two lenses is recommended. The two lenses, 25 mm and 16 mm, are also described in reference 7. The two lenses will allow flexibility in viewing area boundaries and detail size.

Photoperiscope

Design studies have indicated that a photoperiscope is desirable to minimize aircraft structural modifications to allow ease of access and improved optical advantages. This device by Photosonics is described in reference 8, and is the C mount to C mount, 90-degree version.

Mounting Hardware/Installation

The camera-lens mounting structure was designed to provide adequate support and ease of access. Use of the photoperiscope precludes mounting of the AEC drive unit and sensor on the camera faceplate. It must be mounted to sense the illumination. It was also necessary to separate the light sensor head from the drive unit. The sensor unit is attached to the lens support ring and electrically connected to the drive assembly. This modification will be made in-house prior to camera installation.

Timing and Data Correlation

A timing light in the camera provides for imprinting signal data on the edge of the film. Light-emitting diodes (rather than the conventional neon NE-2J lamps) are used in the B-1 systems.

The aircraft data system time code will be imprinted on one film edge and simultaneously on the aircraft instrumentation data tapes where pressure information from the left-hand nacelle is recorded.

A binary-coded test sequence number will be imprinted on the other film edge and simultaneously in the instrumentation data storage. By use of the number-recorded test sequences, identifiable camera runs as short as 1 to 3 seconds can be programmed. This will allow filming many additional test conditions if desired.

Film and Exposure

Eastman Ektachrome film, polyester thin base EFE-2241 is recommended for this program. The DBM-44 camera, a 61-meter (200-feet) capacity model, can use 76-meter (250-foot) loads of the thin base film. A nominal 10,000 frames are available for use at frame rates as desired. The camera speed (frame rate) is adjustable to any speed from 2 to 400 frames per second (fps). Frame rates of approximately 25 fps are expected to be suitable for this program. The 10,000 frames would permit 400 seconds of recording at 25 fps or 40 sequences at 10 seconds each.

No specific recommendations are made for shutter speed at this time. The selected camera has a wide range of available shutters, and a shutter will be selected for optimum image-motion resolution. For example, at 25 fps, a 10-degree shutter provides image-motion resolution to 1.11 ms; a 7-1/2-degree shutter produces 0.83 ms image-motion resolution. Shutter speed will be selected during camera checkout and modification.

Test Section Paint

The test section, except nozzles and interfairing, will be painted matte black for maximum target contrast and reduction of aerial glare. In addition, portions of the aircraft in the vicinity of the camera installation will be painted matte black.

Controls and Electrical

Crew compartment instrumentation controls and displays are currently designed and installed in B-1 air vehicle No. 1. The same units are planned for B-1 air vehicle No. 2 with minor modifications. One such panel is located on a shroud above the instrument panel on the centerline of the aircraft. This panel, shown in figure 6, contains two camera switches labeled "ORD CAMERA" and "CREW CAMERA." This panel is accessible to the pilot or copilot. A second panel, shown in figure 7, is located at the flight test engineer's station and contains two identical switches.

Since the ordnance cameras are not used on air vehicle No. 2, this switch and control wiring will be utilized to actuate the flow visualization camera. Minor modifications will be made to the aft power distribution unit located in the aft avionics compartment. This will include adding an electronic run counter that will advance one count for each actuation of the camera. This code will be gated out to the camera timing lamp and provide a run number identification on the right-hand margin of the film. In addition, the run number will be recorded on the pulse code modulation data acquisition system so that pressure data may be easily correlated with the camera data.

Wiring will be added, as shown in figure 8, from the aft power distribution unit to the camera location. This will include wiring for heaters, run power, automatic exposure control, and correlation.

CAMERA INSTALLATION STUDY

As a result of a detailed study of possible camera locations, the aft portion of the horizontal stabilizer actuator fairing was selected. This is shown as location 7 on figure 9.

Requirements

Several factors were considered. The most important was selection of a location with an unobstructed view. A second major factor was finding a suitable volume within the B-1 to contain the camera and its environmental control provisions. Aircraft flutter was another consideration. If a location were subject to above-threshold vibration, the camera would oscillate. This effect could blur the picture, add an additional motion to the scene, or cause faulty camera operation.

Temperature extremes encountered during the flight profile require environmental control to maintain the film within temperature limits. Most of the candidate locations required cooling since they were not conditioned areas of the air vehicle.

Electric power is required for the camera heater, timing lights, camera drive, automatic exposure control unit, and camera control. These requirements were met by tapping power from an existing power distribution unit in the aft portion of the airplane.

Candidate Locations

The starboard nacelle/nozzle region, including the adjacent side fuselage panels, was the desired view. (See figure 9.) This necessitated an overhead camera position with an unobstructed view. Camera locations were studied, starting from the dorsal fuselage spine and running aft to the tip of the vertical stabilizer toward the aft avionics bay within the aft fuselage. Ten locations were defined. Specifically, they included the aft intermediate fuselage, aft fuselage, vertical stabilizer, and horizontal stabilizer fairing. These 10 locations are shown on figure 9. Table III itemizes the advantages and disadvantages of each location.

Initially, a vertical stabilizer fairing location was studied. After some sizing and packaging, this location was discarded due to package requirements which resulted in a large fairing. This fairing would have had an adverse effect on vertical stabilizer aerodynamics and a potential impact on flutter.

TABLE III.- CAMERA POSITIONS

Location	Advantages	Disadvantages
1. Fuselage. Hinged access door under dorsal spine, ahead of horizontal stabilizer fairing.	• Ample volume • No flutter problem	• Shallow camera view • Requires periscope • Requires cooling
2. Fuselage. Access door under horizontal stabilizer fairing, near stabilizer leading edge.	• Quick access • Ample volume	• Shallow camera view • Requires periscope • Requires cooling
3. Fuselage. Aft avionics bay (top bay above lower rudder and aft of hinge line).	• Air-cooled compartment • Quick access • Ample mounting structure • Ample volume • May tap existing power lines	• Shallow camera view • Requires periscope
4. Horizontal stabilizer fairing. External fairing extension (ahead of stabilizer leading edge below dorsal spine).	• Ample volume	• Possible HF antenna interference • Requires periscope • Must design a fairing • Requires cooling • Aerodynamic drag • Flow separation aft of fairing

TABLE III.- CAMERA POSITIONS - Continued

Location	Advantages	Disadvantages
5. Horizontal stabilizer fairing. Forward position (aft of HF antenna coupler housing).	• Good view of flow visualization area	• Requires cooling • Tight clearances • Requires periscope
6. Horizontal stabilizer fairing. Forward position (above actuators).	• Direct aim capability	• Horizontal stabilizer interference • Requires cooling • Tight clearances • HF antenna interference
7. Horizontal stabilizer actuator fairing. Aft position (above lower rudder and behind horizontal stabilizer spindle).	• Direct aim capability, periscope optional • Cooling air available to aft fuselage • Space available • Access door	• Requires cooling • Tight clearances • Periscope optional but desirable
8. Vertical stabilizer. Dorsal fairing spine.	• No flutter problem	• Requires periscope • Requires cooling • Tight clearances

TABLE III.- CAMERA POSITIONS - Concluded

Location	Advantages	Disadvantages
9. Vertical stabilizer. Midposition on leading edge.	• Direct aim capability • Vision over either side of fuselage	• Flutter, vibration problems • Must design a fairing • Slow access • Flow separation over rudder • HF antenna interference • Decalibration of local strain gages • Lighning strike precludes use of metallic structure • Requires cooling • Aerodynamic drag
10. Vertical stabilizer. Tip pod.	• Direct aim capability • Vision over either side of fuselage	• Flutter, vibration problems • Must design a fairing • Requires liquid cooling (not available on air vehicle No. 2) • Aerodynamic drag • Slow access • Lightning strike precludes use of metallic structure

The other camera locations were studied and discarded, in turn, by using the real air vehicle and a camera mockup. Most locations failed to meet view, structure, or volume requirements. For each location, the camera was placed by assuming a direct shot of the nacelle. Each location was also considered for camera accessibility.

In the later phases of the study, the horizontal stabilizer fairing seemed to offer several possibilities. Consideration of the forward portion was discarded in favor of an aft location with a larger volume.

Earlier locations involving fairings tied to the vertical stabilizer would have experienced severe displacements (during flight maneuvers or transient gust conditions) affecting picture quality. Ideally, the upper fuselage area would have offered the stiffest, most flutter-resistant location. Camera views, fairing airflow turbulence, and packaging volumes precluded the use of this area.

The aft horizontal stabilizer fairing also offers a stiff, flutter-resistant camera location. It is just aft of the massive horizontal spindle support structure and near the stiff base of the vertical stabilizer.

Viewing Study

Two methods were considered for viewing the nozzle/nacelle region from the selected location in the horizontal stabilizer actuator fairing. First, the camera could be oriented to shoot directly at the scene. Second, a periscope could be added to allow orientation flexibility. The periscope method was not selected until a definite need for it was established. A proportionate increase in cost, a larger envelope volume, and a higher installed weight were disadvantages. The large access door just above the proposed location permits easy installation of either proposed camera viewing method.

The direct viewing method can use a small volume, but requires a large cutout through the lower aluminum honeycomb fairing panel. Another problem was the skewness between the camera lens and the fairing lens. The direct view method was discarded for the foregoing reasons and the periscope method was adopted.

A periscope installation was fitted within the horizontal stabilizer fairing. The isolated lens permitted both a small structural cutout and an external fairing which is clear of the horizontal and lower vertical tail at all of their positions during flight.

Structural Details

The camera mount and its environmental provisions are designed of formed sheet aluminum. The external periscope fairing is designed of fiberglass, with a flat plate-glass windshield. To avoid optical internal reflection, the windshield was oriented with respect to the lens. All parts were also designed for removal after the study was completed. The horizontal stabilizer fairing's mold line can be reestablished by flush-capping the periscope hole.

Rework of existing structure has been held to a minimum. Existing fastener locations are used for camera mount attach points and environmental housing panel supports whenever possible. The fairing's honeycomb shell structure requires the most extensive rework. This involves cutting back the aluminum honeycomb, reskinning the cutback, cutting the periscope hole, and fitting a doubler to the panel.

Environmental Control

The camera installed in the vertical tail is temperature-limited, by the film cartridge, to a 322° K (122° F) environment. To maintain this temperature limit, a means must be provided to remove the 250 watts of electrical heat dissipated by the camera plus any aerodynamic heat induced during high-speed flights.

Several options were investigated for protecting the camera from ram-air temperatures as high as 426° K (307° F) and surrounding structural temperatures on the order of 402° K (265° F). The availability of cooling air at the selected camera location was a significant factor in determining the method for removing the electrical heat dissipation and countering the aerodynamic heating effects. The camera is protected from the severe environment by enclosing it with a protective shroud and supplying 305° K (90° F) cooling air. Cooling air is supplied from the stores refrigeration package. This air is controlled to maintain a supply air temperature of 305° ±3° K (90° ±5° F) cooling air. Cooling air is supplied continuously to the camera during all flight and ground conditions when the engines are operating.

The camera and film are protected if the air vehicle environmental control system experiences a failure. In this unlikely event, a warning light in the crew compartment is activated. The pilot is instructed to immediately change air vehicle speed or altitude to a "get home" safe flight regime where ram-air temperatures do not exceed 322° ±6° K (120° ±10° F). The camera power can then be shut off to prevent camera overheating. Cooling air is ducted to the camera from an existing air vehicle cooling air supply line located in the aft fuselage. The 2.54 cm (1-inch) duct from the existing line to the camera will be insulated with 2.54 cm (1-inch) of fiberglass insulation to maintain a supply air temperature as near to 305° K (90° F) as possible. A flow control orifice to make the final adjustment in airflow is incorporated in the duct design. The shroud around the camera provides an air passage around the camera case, thus providing heat transfer from the camera by means of forced convection. Approximately 1.81 kgm/min (4.0 pounds per minute) of airflow will be provided to maintain a maximum exit air temperature from the shroud of 322° K (120° F), 0.907 kgm/min (2.0 pounds per minute) for the 250-watt electrical heat load, and 0.907 kgm/min (2.0 pounds per minute) for the aerodynamic heat load.

Considered in the cooling design are antifogging provisions for the camera window. Fogging could occur during descent from a cold-soaked cruise condition to a moist, warm atmosphere at low altitudes. Fogging is prevented by passing the 305° K to 322° K (90° F to 120° F) shroud exit air over the inner surface of the small camera window before exhausting the air overboard. This is done to keep the window inside surface temperature above the sea level maximum design dewpoint of 302° K (85° F).

Heating for the camera is provided in two ways, one by the fact that 305° K (90° F) air is supplied under all flight conditions, and the second by the heater provisions in the camera.

Electrical Power

Electrical power for the heater and camera will feed from an aft power distribution unit. This unit is located within the left-hand aft avionics bay.

Drawings

Camera installation drawings have been completed and released to file. Rework of existing structure and new parts to be made are shown on the drawings as well as the cooling and electrical provisions. Figure 10 is a pictorial representation of the camera after it has been installed in the airplane, ready for use in the flow visualization study.

CONCLUSIONS

1. Tufts are selected as the most feasible flow visualization devices for use on the right-hand nacelles of the B-1 air vehicle during flight test.

2. Flight research programs to develop flow visualization devices, other than tufts, for use in future flight testing are needed.

3. The Milliken DBM-44 motion picture camera with automatic exposure control and a photoperiscope were selected as the optical equipment for the inflight photography.

4. Two methods of time-coding of the motion picture film will be utilized to permit correlation with simultaneous pressure measurements on the left-hand nacelles of the B-1.

5. The horizontal stabilizer actuator fairing is the most suitable location for a camera to view the tufts on the B-1 nacelles and nozzles.

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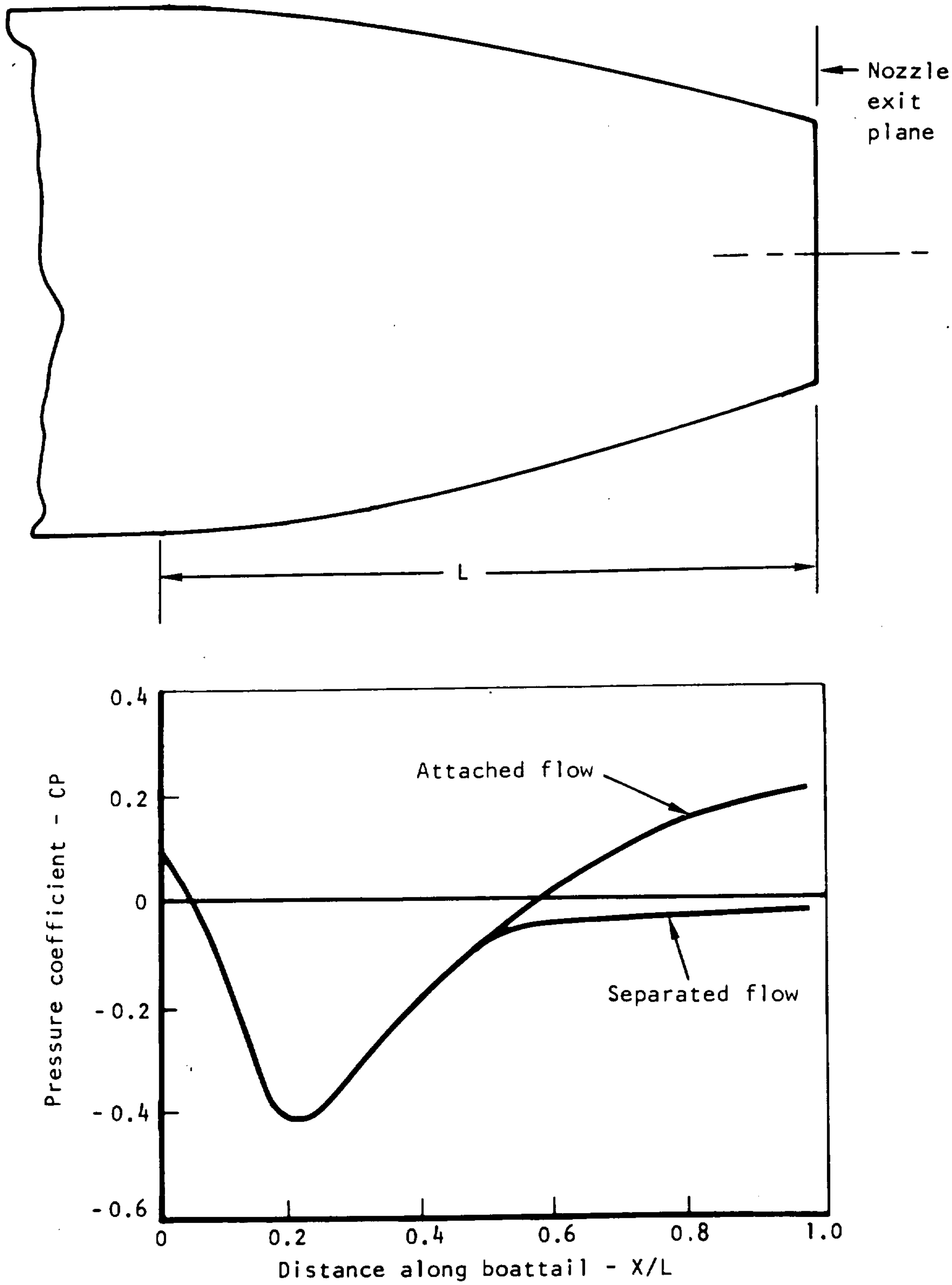

Figure 1.- Typical pressure distribution on boattail nozzle.

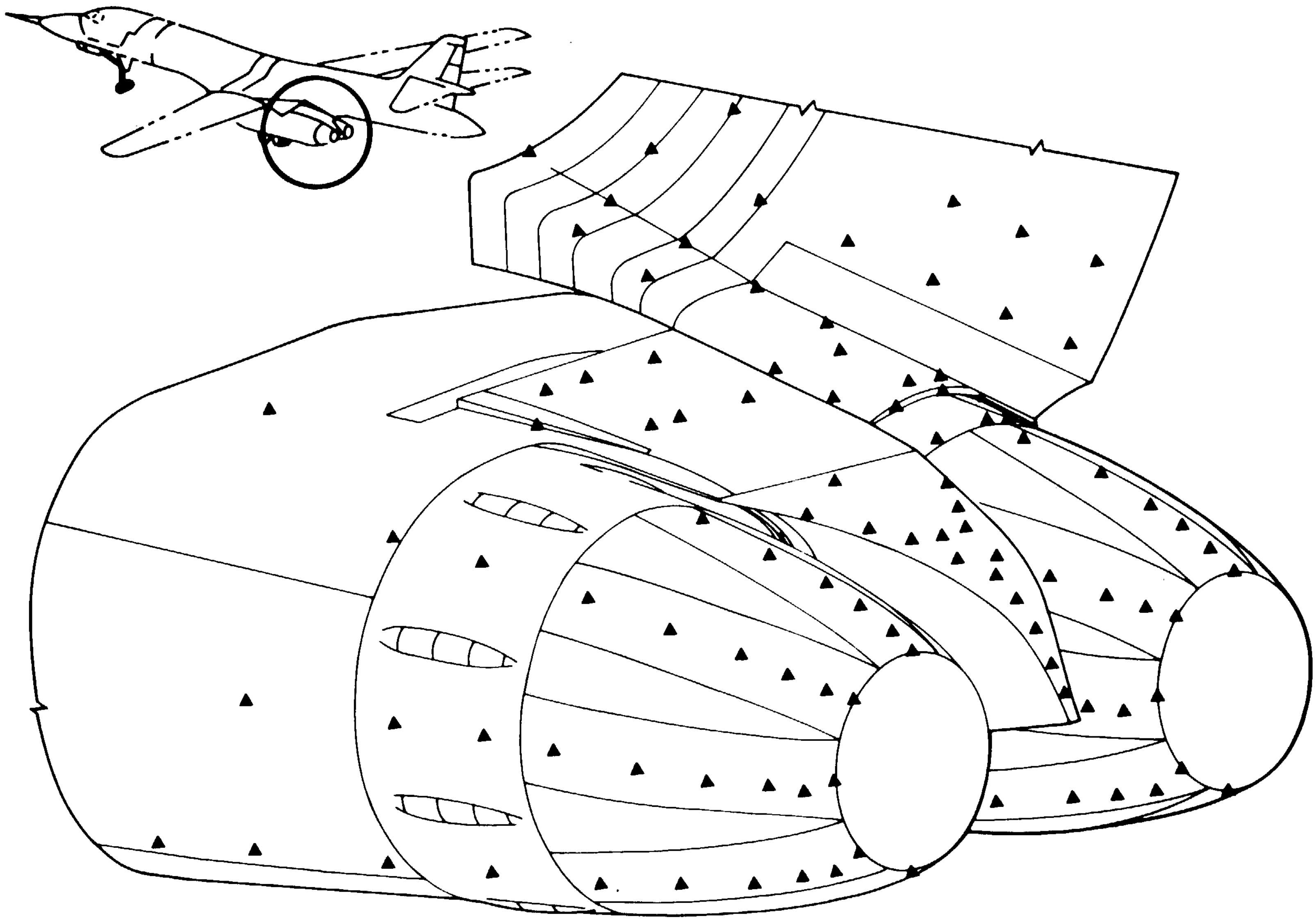

Figure 2.- Aft nacelle isometric showing measurement locations.

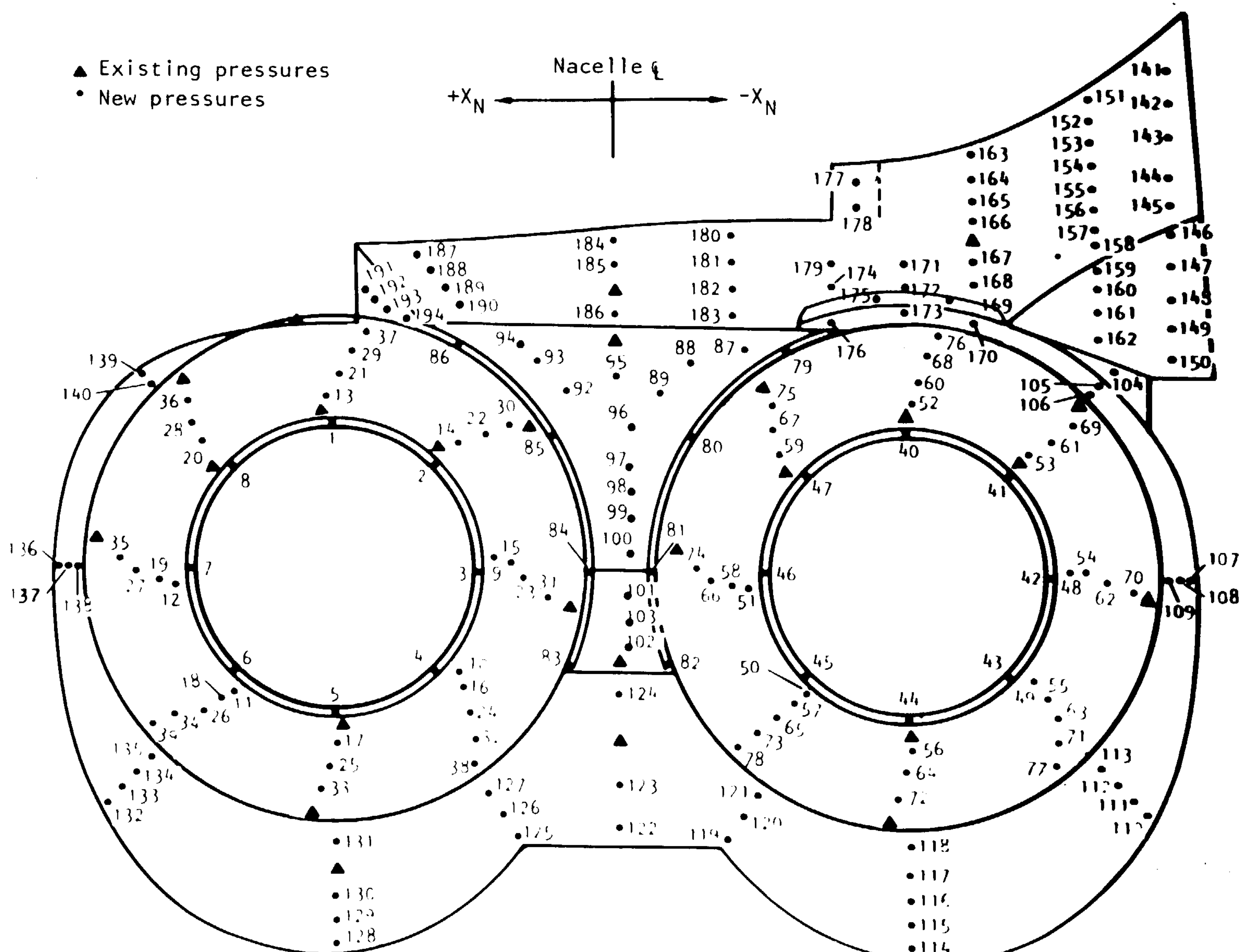

Figure 3.- B-1 air vehicle No. 2 left-hand nozzle/nacelle pressure instrumentation location.

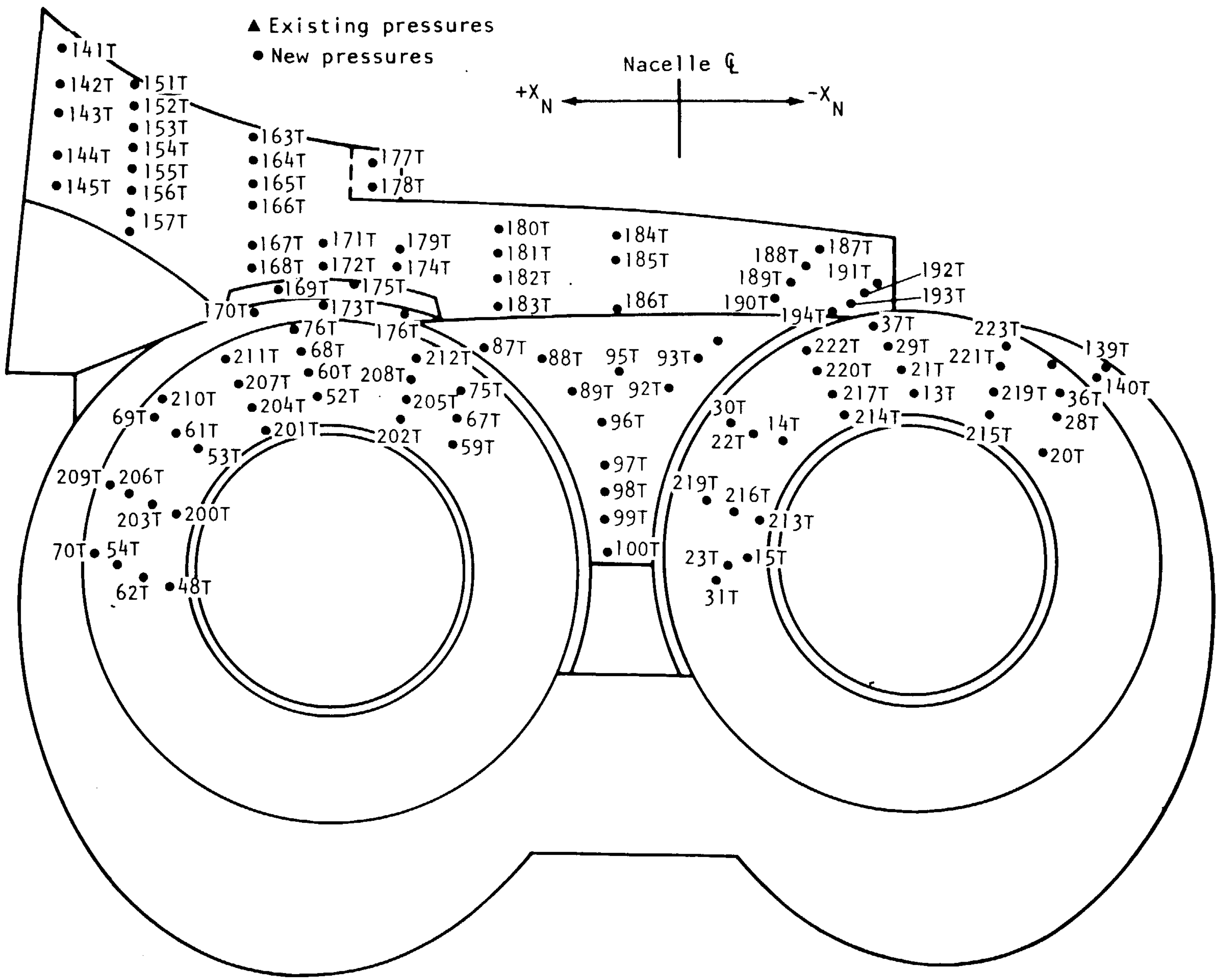

Figure 4.- B-1 air vehicle No. 2 right-hand nozzle/nacelle tuft locations.

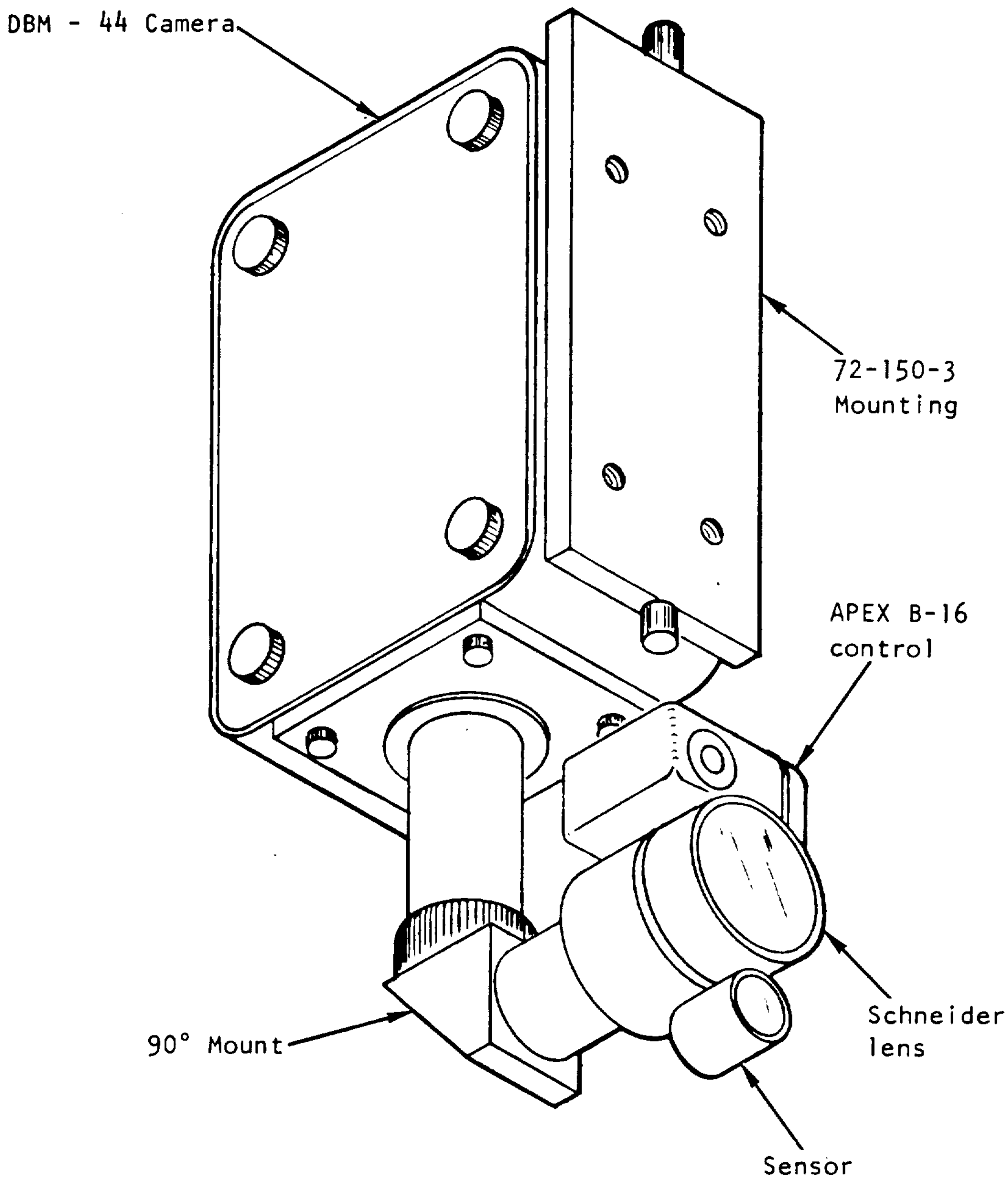

Figure 5.- Camera and accessories

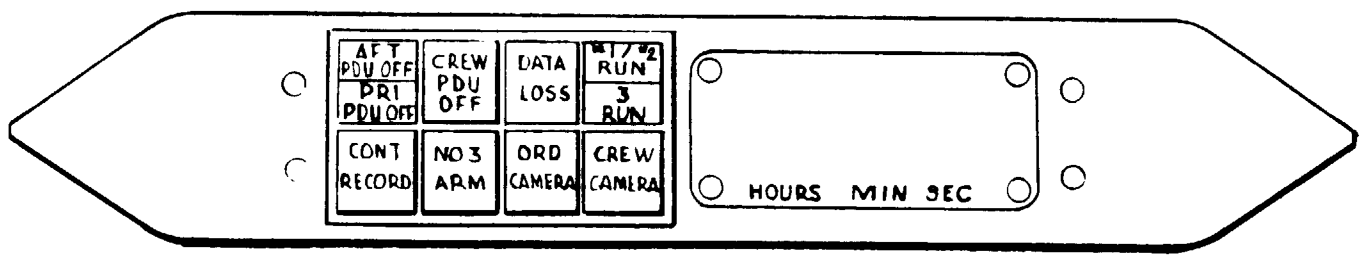

Figure 6.- Control and display - pilot's instrumentation panel. (B-1 drawing number L7500214).

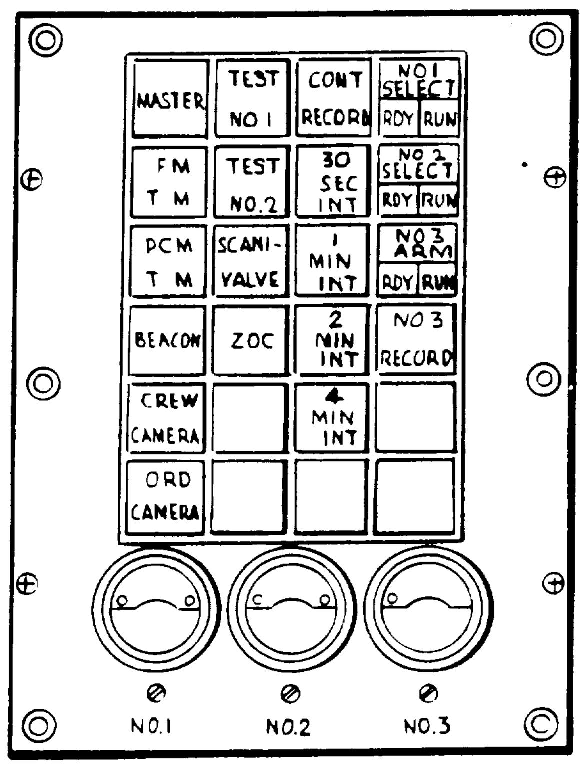

Figure 7.- Instrumentation control panel - flight test engineer station (B-1 drawing number L7500213).

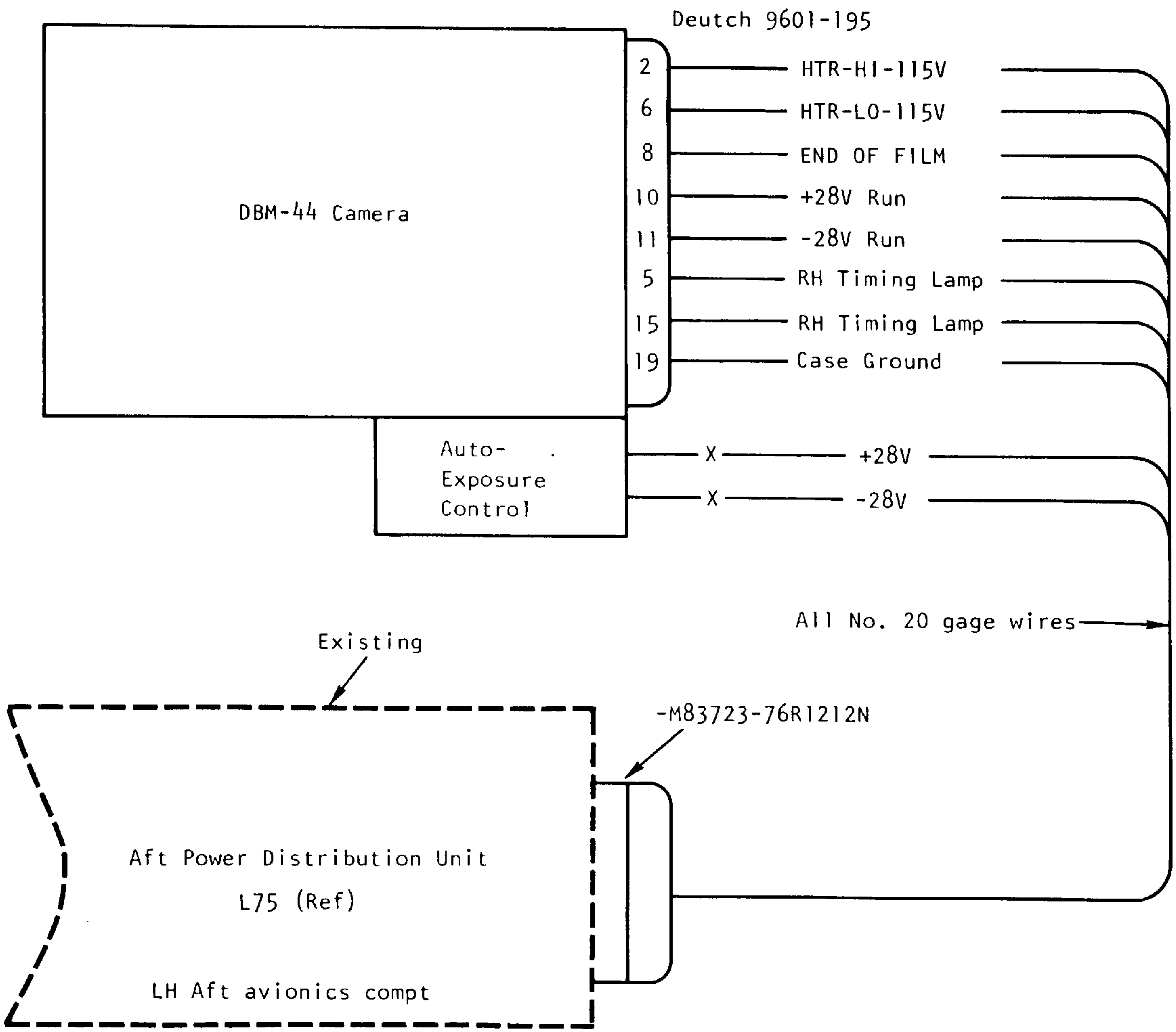

Figure 8.- Wiring schematic.

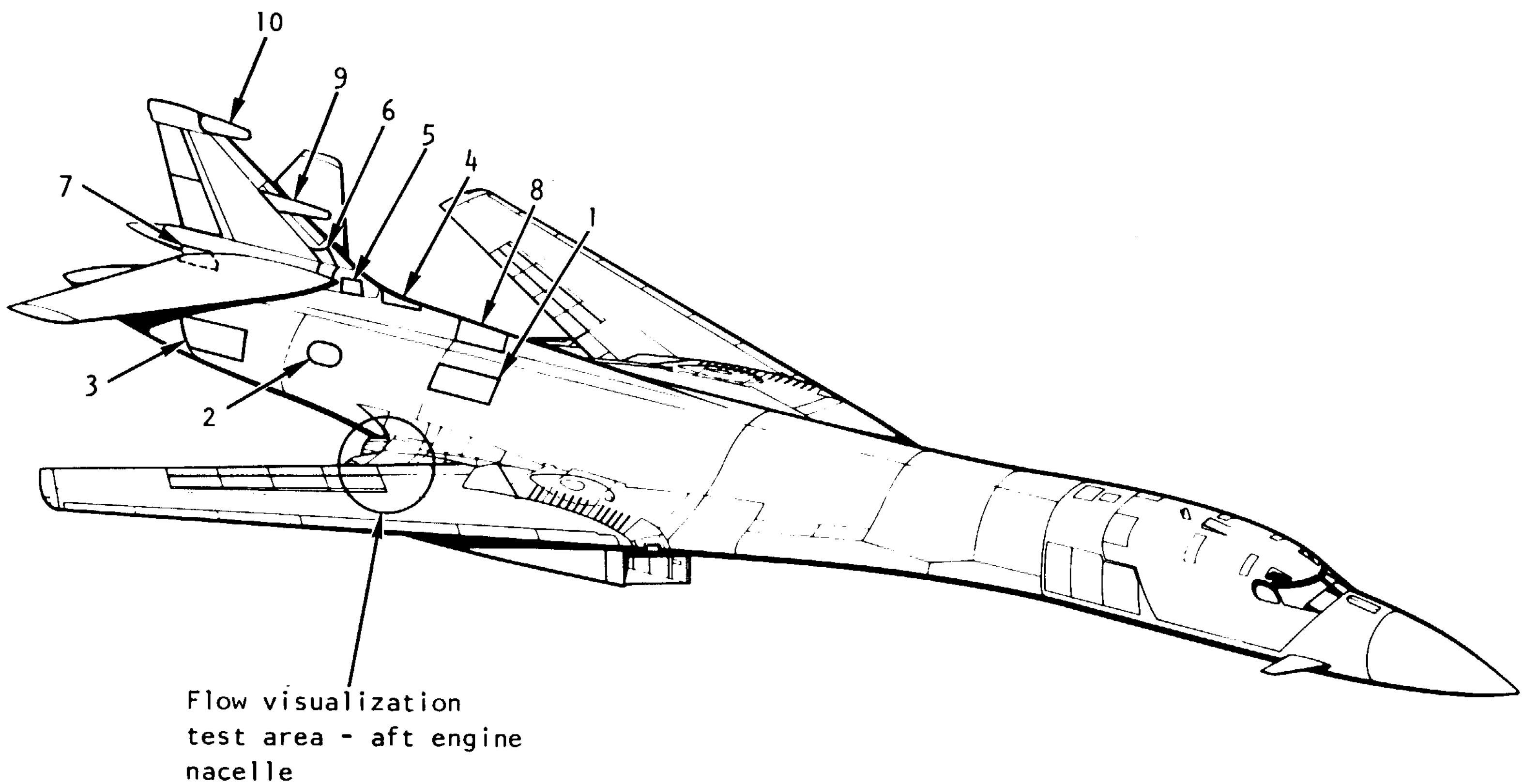

Figure 9.- Possible camera positions.

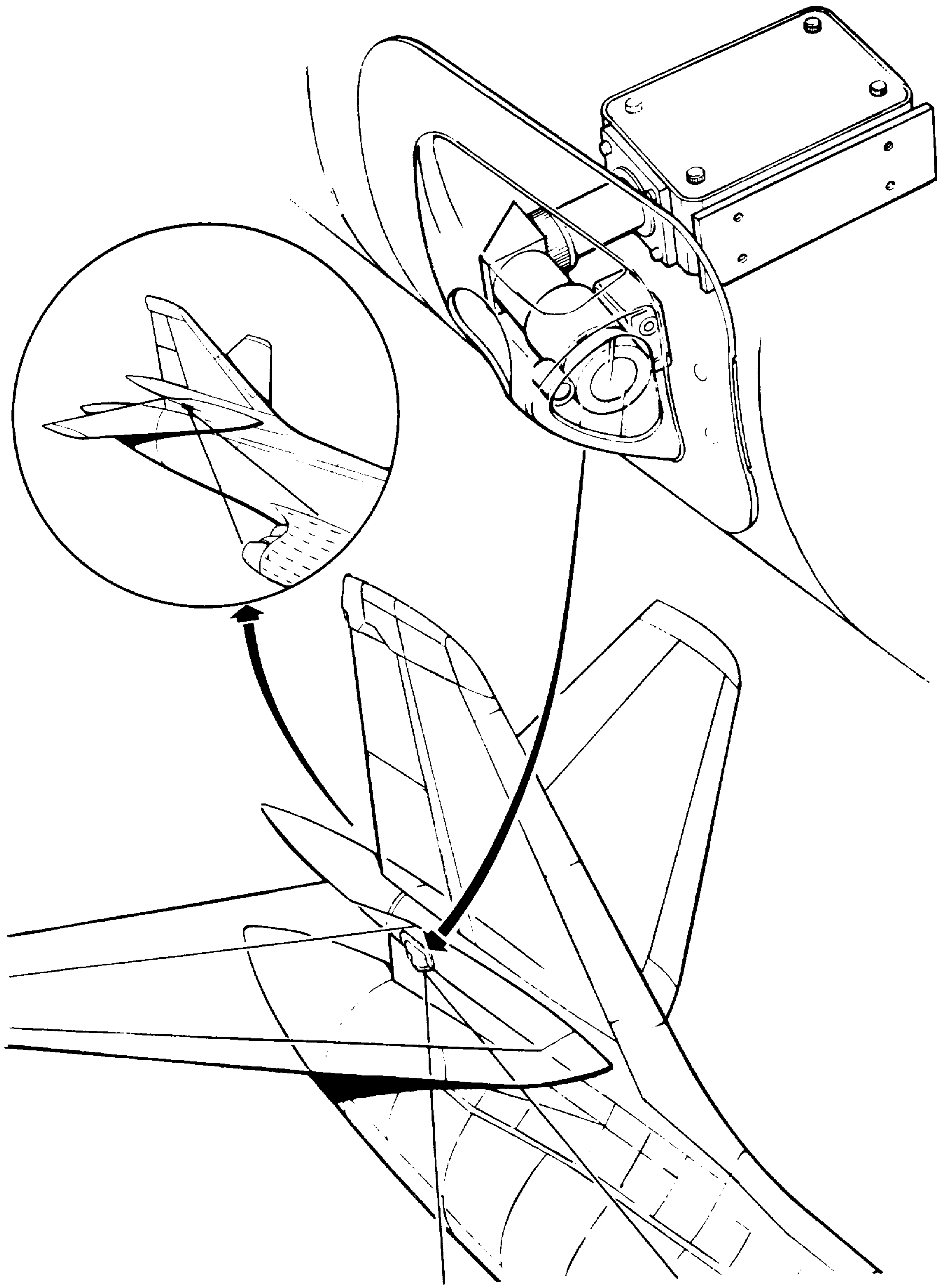

Figure 10. Camera Installation

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16. Abstract

A 2-month program was conducted to perform engineering evaluation and design tasks to prepare for visualization and photography of the airflow along the aft portion of the B-1 nacelles and nozzles during flight test. Several methods of visualizing the flow were investigated and compared with respect to cost, impact of the device on the flow patterns, suitability for use in the flight environment, and operability throughout the flight. Data were based on a literature search and discussions with the test personnel. Tufts were selected as the flow visualization device in preference to several other devices studied. A tuft installation pattern has been prepared for the right-hand aft nacelle area of B-1 air vehicle No. 2.

Flight research programs to develop flow visualization devices other than tufts for use in future testing are recommended.

A design study was conducted to select a suitable motion picture camera, to select the camera location, and to prepare engineering drawings sufficient to permit installation of the camera. Ten locations on the air vehicle were evaluated before the selection of the location in the horizontal stabilizer actuator fairing. The considerations included cost, camera angle, available volume, environmental control, flutter impact, and interference with antennas or other instrumentation.

17. Key Words (Suggested by Author(s))

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Aft nacelle flow visualization

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