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16. Abstract

A series of test, using a F-111 aircraft fuselage, was conducted to determine local and overall airflow patterns within its engine bay by visual means. Portions of the interior of the right-hand engine bay were made directly observable by the use of transparent Lexan windows which were installed in the nacelle doors. Yarn tufts were secured to the engine case, accessories, and inner nacelle wall in areas where they could be viewed and photographed through the Lexan windows. The airflow rate through the engine bay was varied to simulate different flight speeds. The data revealed airflow patterns ranging from simple fore-to-aft flow to complex flow patterns characterized by different flow directions between the engine case and nacelle wall at the same fuselage station; flow reversals; and abrupt changes in direction.

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INTRODUCTION

PURPOSE.

The purpose of this test program was to define airflow patterns by visual means within the F-111 engine bay with and without flapper doors. on the forward firewall

BACKGROUND.

The F-111 is a Mach 2 class, fuselage-mounted twin engine aircraft powered by TF-30 axial flow turbofan engines with after burning.

A unique feature of the F-111 aircraft is its vertical aerodynamic firewall located at fuselage station (FS) 593. This firewall consists of hinge-mounted, free-floating metal doors which are normally closed by gravity when the aircraft is on the ground and the engines off. These doors (termed flapper doors) are held open by the normal flow of air into the engine bay when in flight and presumably by aspirated air, due to ejector pumping when the aircraft is on the ground and the engines are operating.

Figure 6 of ~~report JTCG/AS-74-T-002~~ depicts (~~General Dynamics, Environmental and Operating Requirements for Fire Extinguishing Systems on Advanced Aircraft, by J. D. McClure and R. J. Springer, Fort Worth, Texas (JTCG/AS-74-T-002)~~) ~~depicts~~ and engine bay airflow pattern where air, entering through the flapper doors follows a helical pattern before exiting aft. This pattern traces a path over the top of the engine toward the outboard side resulting in a clockwise flow through the right-hand nacelle (looking forward) and counter clockwise through the left-hand nacelle.

Since the flapper door hinges are not horizontal, these doors open at an angle and hence the supposition that airflow will assume a helical pattern.

Since the F-111 was entered into service, the flapper doors have been removed from all of these aircraft. The constant cycling of the doors have caused some to break loose, presenting a hazard and maintenance problem. Therefore, their elimination removed this problem, but it also removed the cause of the theoretical helical airflow pattern. This test program was designed to provide an insight into local and overall airflow patterns within the F-111 engine bay through a wide range of simulated flight conditions with these flapper doors installed and removed.

TEST ARTICLE DESCRIPTION.

The test article used for these airflow visualization tests was a F-111A, sequence 20 aircraft manufactured by the General Dynamics Corporation, serial number 65-5702. ~~Figure 1 shows the F-111 fuselage being off-loaded from a Navy cargo ship at the Military Ocean Terminal, Bayonne, New Jersey.~~ The fuselage ~~was~~ acquired ~~through Wright-Patterson AFB from Davis-Monthan AFB and~~ was devoid of instrumentation, engines, landing gear and systems. The weight of the fuselage as received was 20,200 lbs. The length, width and height were 77 ft., 13 ft-7 in, and 12 ft-8 in, respectively.

The F-111 fuselage required considerable modification to meet the needs of the airflow visualization test program and subsequent test programs which are planned for this test article. Since it was required that the fuselage be moved perodically as the need dictated, it was necessary to make it mobile. An undercarriage or "main gear" was fabricated using 4 in. steel pipe and subsequently fitted with

.... a helical pattern. The nacelle, further, incorporates a design concept whereby a unidirectional aft air flow, whose velocity exceeds that of the flame propagation rate of a hydrocarbon fuel, will preclude forward flame propagation. Additionally, this concept will result in a flame proceeding aft until it is blown out the rear of the nacelle

DC-3 main landing gear wheels. Figures 2 and 3 show the device that served as the "main gear." A nose gear obtained from China Lake Naval Weapons Center was also installed. Since the nose gear was from a Navy version of the F-111, modifications were necessary for a suitable fit. A brace was installed on the nose gear strut to preclude its collapsing.

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An operable TF-30 engine was installed in the test article although its operation was not required for the airflow visualization studies. [Its operation will, however, be necessary for the other phases of testing.] An actual engine rather than a simulated or "boiler plate" engine was installed to provide for a more realistic environment. [The engine that became available at ths program's inception was a TF-30-P1, less afterburner. The engine that was normally installed in this aircaft was a model P3. The side of the test article that was visible from the operations area was the right-hand side. Therefore, a right-hand P3 buildup kit was acquired and installed at Pease AFB using Air Force facilities and personnel. Likewise, a P3 afterburner was acquired and installed at Pease AFB. Because of the unavailability of a P3 afterburner kit, a P7 kit was used, but required modifications to fit the test article engine installation. This was also accomplished at Pease AFB. The afterburner was non-functioning and its incorporation into the test article was to serve as a realistic environment for these airflow studies. It was necessary to further modify the afterburner to make the test article confirm to the current configuration. This involved the installation of a modification kit with larger blow-out doors, narrower struts, and springs which held the doors closed in the static condition. With the orginal configuration, the doors were free-floating and in flight assumed a position as the aerodynamic conditions dictated. The installation of this afterburner kit was accomplished with the supervision and assistance of Tinker AFB personnel. As a matter

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of interest, the presence of these spring-loaded blow-out doors resulted in higher static pressure within the engine bay as compared to the original configuration during airflow operations. Figure 4 shows the right-hand engine bay less nacelle doors and TF-30 engine. Figure 5 shows the TF-30 mounted on an installation dolly. before the after burner modification kit was installed. Note that the two blow-out doors near the top of the afterburner are closed while the lower one is open. After the kit installation, all of these doors were spring-loaded closed.

Further modifications were required in order to mate the F-111 test article to the Airflow Facility, which is described in a subsequent portion of this report. The inlet spike was removed resulting in an engine bay air inlet configuration of an approximate 7 in. x 32 in. rectangle. A transition ~~piece~~ was fabricated and mated to this rectangular splitter inlet. This transition section gradually assumed a circular cross-section 18 in. in diameter which was, in turn, joined to the main air supply duct. Figure 6 shows the test article on the test pad before mating to the air supply duct; Figure 7 shows the air supply duct and transition section in place.

The F-111 fuselage has a number of paths through which air entering the splitter inlet may take. In order to assure that, to the maximum extent possible, all measured airflow passing through the 18 in. air supply duct was ventilating the engine bay, these other flow-paths were sealed by mutual agreement with Wright-Patterson AFB. This included sealing the environmental control system duct, hydraulic oil cooler duct, vents under the fuselage and openings between the engine bay and main gear storage bay. Further modifications to airflow paths were necessary to bring the F-111 test article as close to the current F-111 configuration as possible. Air that would normaly enter the glove area inlet of the test article (if flying) had two exit paths: through the flapper doors into the engine bay and overboard at the main wing pilot area. In current F-111's, the air entering the glove area inlet does not mix with boundary layer air entering the splitter inlet, but rather it all exits overboard at the wing pivot area without any portion venting the engine bay. On the F-111 test article, therefore, it was necessary to isolate the glove area to preclude any of the air that was being ducted into the splitter inlet from dumping overboard at the glove inlet and wing pivot areas. This was verified with General Dynamics as reasonable fix in making the test article more closely resemble current F-111's. This isolation was accomplished by gaining access to the inner glove area by removing the right-hand upper nacelle cover and installing a plate behind the inlet aft of the pivot.

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With these modifications, the measured air flow entering the splitter inlet would ventilate the engine bay without any portion being dumped overboard before exiting aft. However, leakage does occur around engine bay doors and panels which is normal. The amount of this leakage is not known. Furthermore air leakage probably dose vary among F-111's depending upon such variables as production tolerances, seal condition, flight conditions etc.

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The F-111 fuselage as received by the FAA Technical Center had all flapper doors intact. Current F-111's have had these doors removed. Since testing would be conducted with these doors both installed and removed, provisions had to be made to remove and install the flapper doors as the test conditions required. Figures 8 and 9 show the right and left hand engine bays, respectively, viewing forward through the inlet. The left side shows the configuration of the flapper doors which are in place in (figure 9).

Since defining the engine bay airflow patterns was by visual means, it was necessary to make as much of the inner nacelle area visible as possible for personal observation and photography. Portions of the engine bay doors and panels were cut out and replaced with clear, colorless Lexan windows. This was accomplished on the right and underside of the aircraft fuselage. Because of the twin engine design, observation windows were not possible on the inboard side nor was it feasible to install windows on the upper engine bay. Figures 23 and 24 show the extent of the visibility of the interior of the engine bay and these will be discussed further in this report. The viewing windows were loated between FS 595 and FS 760 within the 3/6 o'clock quadrant (looking forward). Yarn tufts, 2 inches long, were secured to the engine case, accessories and inner nacelle wall ~~with aluminum tape~~. Figure 10 shows the test article with some of the nacelle doors off or open, revealing the engine bay and TF-30 with some of the tufts in place. The tufts on or near the engine case were of a different color than those on the nner nacelle wall (or viewing windows). This would allow a more accurate interpretation of airflow patterns when viewing the test motion pictures, still photos, video tape and/or personal on-site observation. This provided an aid in differentiating between flow patterns at or near the engine surface from that occuring along the nacelle wall. Additionally, provisions were made to introduce CO_2 into the engine bay as a visualization medium to supplement that data gleaned from the tufts. A copper tube 5/8 in. in diameter was installed with the open end just forward of the aerodynamic firewall. The source of the CO_2 was a 50-pound fire extinguisher. The expansion horn was removed and the hose plumbed directly into the copper tube, the open end of which was located behind a flapper door opening at approximately the 3 o'clock position. Selecting this location as the entry for the CO2 is discussed in Discussion of Test Results. Since the space under the fuselage was limited, photographing through the windows on the underside was accomplished using mirrors.

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"......aircraft fuselage. Care was taken to assure that the presence of these windows did not alter the interior nacelle configuration which could affect airflow patterns. Because....."

A frame was fabricated on which was mounted four 4 ft x 4 ft mirrors so that the reflecting surface was 4 ft x 16 ft.

AIRFLOW TEST FACILITY DESRIPTION

The Airflow Test Facility is an outdoor test site which can be utilized for small-scale and large or full-scale test programs. The major features of this facility are a YTF-33 turbofan engine and a 75 ft x 100 ft test pad. The YTF-33 is of the external bypass type capable of pumping air at a rate of 200 lb/sec through the fan. Because of the external bypass design, the air provided for test is devoid of combustion products. Air is ducted from the YTF-33 to the test pad through a 30-inch diameter duct and velocities can exceed 400 knots (kts) in the duct. Figures 11 and 12 are two views of this test facility which show this duct mated to the F-111 test article. The YTF-33 is housed in an engine enclosure building located at the lower right in figure 12. For this test program the 30-inch duct is necked down to 18 inches in diameter and mated to the transition section which is joined to the F-111 engine bay inlet. The excess air is vented to atmosphere via Y-section in the main duct. This feature is shown in both figures 11 and 12. Airflow is controlled by the YTF-33 engine speed and gates in the main and bypass ducts. [The F-111 is secured to the large test pad. Note that a smaller 25 ft x 25 ft test pad is located in front of the larger pad. At one corner of the larger pad is a 6000-gallon catch basin. When testing requires flammables which may spill onto the pad and ignite under the test article, a water deluge system can flood the pad with 3000 gallons of water in less than one minute. The slope of the pad carries the water and flammables to the catch basin. This capability was not required for this test program since the TF-30 was not operating nor were there flammables involved. The water deluge system is shown in operation in figure 13.] delete

TEST DESCRIPTION.

All tests were conducted in like manner. For tests exceeding 9 lb/sec airflow, the main duct gate was full open. For tests under 9 lb/sec, the main duct gate was in a partially closed position. This was necessary since the airflow rate through the F-111 engine bay exceeded 9 lb/sec with the YTF-33 air supply engine at idle speed and gate open. The YTF-33 was not operated below idle.

These airflow visualization tests were conducted in two phases: flapper doors installed and flapper doors removed. A typical sequence of events involved starting the YTF-33, bringing it up to the desired speed and activating the cameras. During the course of testing, CO_2 was introduced behind the flapper door opening at approximately the 3 o'clock position and directed aft. Sixteen mm color motion pictures were taken as well as color photographs and recordings on color video tape.

Airflow visualization tests were conducted with two ventilation rates: a low of 7 lb/sec and a high of 22 lb/sec. Lower, intermediate and higher flow rates were originally planned but were eventually eliminated for reasons discussed in the Discussion of Test Results.

DISCUSSION OF TEST RESULTS (FLAPPER DOORS INSTALLED)

Airflow patterns within the F-111 engine bay were observable in a limited area of the outboard and underside portions of the right-hand nacelle as noted in the Test Article Description. For this reason an attempt to define the airflow patterns for the entire 360° of the bay ~~cannot~~ could not be made.

The first phase of testing was accomplished with the flapper doors installed. The maximum engine bay ventilation rate was limited to 22 lb/sec, since the Lexan windows were susceptible to damage above this rate. During preliminary testing at higher flow rates, a number of windows were damaged or became loose ~~blew out~~. The windows were subsequently replaced with their restraints reinforced. The maximum ventilation rate was consequently reduced to a level that could be tolerated on a continuous operation basis without window damage.

Included in the original test schedule were airflow visualization tests in the range from a minimum which occurs at ground idle (2.6 lb/sec) to a maximum of 35 lb/sec which occurs at a sea level dash (Mach 1.2) condition. For practical considerations the higher flow rate was reduced as noted previously. The lower flow of 7 lb/sec was established after some preliminary study. In order to initially obtain some sense of the variation to airflow patterns that could occur at various simulated flight conditions, a record of tuft orientation was taken with the use of a color video camera. The ventilation rate was slowly increased from 2.6 to 22 lb/sec. Including the lowest extreme of airflow (2.6 lb/sec) in the test program would have provided no useful data. The air flow within the engine bay was at such a low velocity that most tufts were hanging under their own weight and could not provide a true picture of flow patterns. Attempts were made to find a commercially available lighter weight yarn that was both large enough in diameter and sufficiently bright in color to be photographed at a distance. Photographic personnel assisted in the selection of the yarn which was a Polyester rug yarn whose weight was 46.78 grams/70 yards.)

As the ventilation rate was increased and the tufts began to assume more closely the airflow pattern, further increasing the ventilation rate had little or no apparent effect on tuft orientation. Some tufts did display an increase in oscillation frequency as the air became more tubulent, but without a change in orientation. The minimum flow rate of 7 lb/sec, therefore, was selected and represents the ventilation rate at the cruise condition. It was considered more meaningful to select a rate which approximates an actual flight condition than some arbitrary value. The 22 lb/sec ~~does~~ did not represent ~~and~~ any particular flight condition but was a necessary self-imposed limit. The ventilation rates at various flight conditions as provided by General Dynamic Corp. are shown in table 1.

TABLE 1. F-111 ENGINE BAY VENTILATION RATES

Ventilation Rate (Lb/Sec)	Flight condition
2.6	Ground Idle
7.0	Cruise
9.0	Landing Approach
11.3	Take-Off
14.0	Holding Pattern
35.0	Sea Level Dash (Mach 1.2)

Through a piping arrangement, CO_2 was introduced behind a flapper door opening at the 3 o'clock position (looking forward) and its path observed. Before confirming the 3 o'clock position as the permanent location for CO_2 entry, it was introduced at the 11 and 1 o'clock positions during preliminary testing. Although this procedure was conducted as part of preliminary tests, it nevertheless provided ~~interesting~~ meaningful results. The CO_2 was not observable when it was introduced at either of these locations. This procedure was repeated several times to verify ~~results~~ observations. The ~~outcome~~ result was the same. This gave a positive indication that the CO_2 (and air) entering through the aerodynamic firewall at the 11 and 1 o'clock positions did not follow a path where it could eventually be observed through the windows. If there was a helical flow initiated by the angle of the open flapper doors it was very quickly reoriented to a near fore-to-aft direction. Theoretical concepts proposed by General Dynamics trace a helical path over the top of the engine toward the outboard side (where the viewing windows are located). Since the CO_2 was not observed in any run where it was introduced at either the 11 or 1 o'clock position, it must be assumed that it became reoriented to a fore-to-aft direction or followed an unkown path through the unobservable portion of the engine bay. CO_2 was, also, introduced through the onboard bifurcated engine bay fire extinguishing nozzle. This did not prove to be a useful approach since the CO_2 was not introduced parallel to the incoming air stream. The CO_2 mixed very rapidly with ventilating air and its path could not readily be traced. The 3 o'clock position with CO_2 entry parallel to the engine was selected as the most practical means to introduce the CO_2. The fact, however .... See P 11A

During the 7-lb/sec test condition, the CO_2 was observed to take a slight wave-like path which was bearly discernable and which peaked at approximately FS 675. An examination of still photographs showing tuft orientation along the nacelle wall

.... CO_2. The fact, however, that a clearly defined path could not be traced when the CO_2 was introduced through the on-board extinguishing nozzle, but rather an apparent mixing, did give some insight into extinguishant movement. The extent and thoroughness of this mixing, however, was beyond the scope of these studies. A thorough probing of the nacelle volume adjacent to the aerodynamic firewall during agent concentration studies of the F-111 is recommended. This was an area of unusual flow patterns that will be described in more detail further in this report. Also, since the CO_2 was not observable when introduced at the 1 and 11 o'clock positions, a thorough probing is recommended at the top of the engine compartment. The theoretical helical flow pattern could enhance mixing, but its apparent absence introduces a measure of doubt regarding the thoroughness of agent mixing.

does tend to support this wave-like pattern. The opaqueness of the CO_2 precluded any observation of its behavior beyond the inner nacelle wall and therefore matching CO_2 flow with tufts secured to the engine case was not possible. The path of the CO_2 was generally more closely aligned with the tufts secured to the inner nacelle wall and viewing windows than those secured to the engine case. The path of the CO_2 aft of the rear engine mount appeared to be virtually horizontal, i.e., fore-to-aft. The fact that the CO_2 expanded greatly after exiting the 5/8 inch copper tube and mixed with the ventilating air made a precise trace of its path difficult. During the 22-lb/sec test condition, the path of the CO_2 was even more difficult to observe and the wave-life pattern was not discernible. The visual recorded media indicated a virtual horizontal flow. It was possible that at this higher simulated airspeed, this wave-like pattern either did not exist or was not discernible with the techniques used. Note however that the CO_2 did not substantiate a helical airflow path whether the flapper doors were installed or removed.

Tuft orientation provided a greater insight regarding airflow patterns then did the CO_2 path. One note-worthy aspect was the marked difference between the airflow patterns along the inner nacelle wall and adjacent engine case, in some areas. Generally the flow along the inner nacelle wall was relatively even without abrupt changes in direction, as indicated by tufts secured in these areas and was the path observed to be taken by the CO_2. In contrast, the tufts secured to the engine case, accessories, and lines indicated more diverse patterns, but was not discernible by observing the CO_2. Figures 14 and 15 cover a view of the test article nacelle between approximately FS 655 and 720: figure 14 showing tuft orientation at a ventilation rate of 7 lb/sec and figure 15 at 22 lb/sec. Since the black and white figures do not permit the reader to identify color, the tufts secured to the nacelle wall (and window) were red and those on the engine case and accessories were yellow or blue. Note the similarity in tuft orientation in both figures, although in figure 15 the ventilation rate is considerably higher. Those tufts on the observable engine case were angled aft and downward at both flow conditions. The tufts on the inner nacelle wall were oriented in a virtual fore-to-aft direction revealing the rather complicated airflow patterns within the engine bay. In this case the complexity is manifested by the airflow directions varying within the narrow space between the engine case and nacelle wall. Although not readily noticeable in figures 14 and 15, the flow at the engine surface takes an abrupt change in direction at the rear engine mount-flange (approximately FS 700). The tufts located just forward of the engine mount (at the 3 o'clock position) were oriented vertically downward. Indications were that air approached this area at a slight downward angle and apparently was defleted vertically downward as it inpinged on the engine mount-flange. The tufts located just aft of the flange were oriented vertically upward. The tufts in the same area, but located on the nacelle wall, were oriented in a virtual fore-to-aft direction. with these .... p 13A

Figures 16 and 17 show tuft orientation along the outboard side between FS 730 and FS 760 for ventilation rates of 7 and 22 lb/sec, respectively. In this area (afterburner) the tufts indicate a near fore-to-aft direction except near the 5 o'clock position at FS 740 (bottom right of figure) where the tufts are angled slightly upward. Note the similarity between the two figures although, in figure 17 the flow is 22 lb/sec. The window at the left in these figures (FS 750) indicated near horizontal flow by all tufts. Figures 18 and 19 cover the same fuselage station location as 16 and 17 but under the test article. The flow of air is parallel to the afterburner case in both figures. The flow, in fact was parallel to the engine case for virtually the entire length of the lower nacelle with

Page 13, Para 1, add at end of para.

With these complicated flow patterns, it is difficult to predict what path a fire may take or how the patterns could affect agent concentration/distribution. Since tuft orientation did not appear to indicate inter-mixing between flow at the nacelle wall and engine case, it is possible that agent entrained in the flow along the nacelle wall may be ineffective on a fire near the engine case. This speculation can be quelled by probing such areas during agent concentration studies. In such instances, it would be necessary to place a probe at the engine case and another at the nacelle wall at the same fuselage station and clock position.

one major exception, which will be discussed further in this report. Generally, flow aft of the rear engine mount displayed less complicated patterns within the observable engine bay and was oriented in a near fore-to-aft direction with the exception of that area at FS 740 near the 5 o'clock position. This can be.... p14A

Perhaps the most significant area within the observable engine bay was located between FS 595 and FS 610 (just aft of the aerodynamic firewall) below the engine. Figures 20 and 21 depict this area between approximately the 4 and 6 o'clock position. The number "2" marked on the window is for identification purposes and the arrow under the "2" was marked to show the horizontal or fore-to-aft direction. Note that no tuft indicates a predominant flow direction. This was the only portion below the observable engine bay where flow was not oriented in the aft direction: the exception noted in the previous paragraph. The tufts toward the top of figure 20 (7 lb/sec) were oriented downward and slightly forward while those at the lower portion of the window were oriented upward and forward. This indicated a flow tendency opposite that of the general overall air stream. The tuft secured to the flexible coupling that passes approximately through the middle of the figure was oriented aft and the tuft secured to the window in the same area was oriented aft and downward. The tuft mounted aft of the flexible coupling was oriented downward. This tuft alignment suggests a multi-directional flow pattern in a rather confined volume of the engine bay.

At a ventilation rate of 22 lb/sec in this same area (figure 21), i.e., just aft of the firewall below the engine, the apparent reverse flow phenomenom became more pronounced and the volume affected appeared larger than at the lower airflow rate. Those tufts toward the top of the figure (approximately 4 o'clock) were oriented forward and upward as compared to these same tufts which were oriented downward and

Page 14, para 1, add at end of para

This can be attributed to a large degree to the absence of protrusions into the ventilating air stream. Such a condition allows unobstructed air flow and additionally eliminates flame holders.

forward at the lower flow rate. The tufts secured to the lines closest to the fire wall (right of figure) were oriented downward and forward. Again, the tuft alignment suggests a multi-directional flow pattern with tendency toward reverse flow.

In an attempt to reconcile this aberrant airflow behavior, one must consider the configuration of the aerodynamic firewall. Refer to figures 8 and 9. There are no flapper door openings through the lower portion of the firewall. In fact the bottom of the firewall is a somewhat solid structure which accomodates the bulkhead fittings for the various lines (eg. fuel, electrical, extinguishing agent,.etc.) and through which no air passes. In figure 8, which is a photograph of the right-hand bay and the side which is the subject of this report, note that the flapper door openings circle over the top of the engine bay between approximately 7 and 4 o'clock. Since air can enter only through the top portion of the firewall and not the bottom, it is surmised that an area of reduced pressure is created below the engine in this area. As the air enters the nacelle through the openings at the top of the firewall, its natural tendency would be to curl around and fill the low pressure space below the engine. At higher ventilation rates, the air enters with a higher inertia and thus carries further downstream before reversing direction. This could account for the variation of tuft orientation in this area and, also, account for the apparent larger space that is affected by the reverse flow phenomenon. What has been referred to as reverse flow ~~was more likely to~~ could possibly have been a circulatory air motion as it cascades downward. For true reverse flow to occur, i.e., travel at least a short distance against the mainstream, the air would have to re-enter the plenum. ~~Since~~ Although there is a positive pressure in the plenum, ~~it appears unlikely~~ these tests did not confirm or negate that the air was re-entering the plenum. If the pressure diffential was such so as to provide a condition allowing reverse flow, the flapper doors would close precluding air from re-entering the plenum. From personal obervations and from the visual recorded media none of the observable flapper doors were closed. What is surmised to have occured in this area was that air entered through the top portion of the firewall, the flow was induced downward by a low pressure area below the engine and impinged on the lower nacelle wall. At this point, the air stream divided with a portion reversing it direction by curling forward and impinging on the lower portion of the firewall. This process resulted in a counter clockwise motion of air under the forward portion of the engine. The remainder of the air was deflected rearward and upward as it impinged on the lower nacelle wall. This flow pattern was evidenced with and without flapper doors at all ventilation rates. A pictorial description of this hypothesis is shown in figure 41 and was in fact based on tuft orientation for the 22 lb/sec flow rate without flapper doors and will be discussed further in this report.

The aberrant flow pattern that occurs adjacent to the lower portion of the aerodynamic firewall could present a matter of concern. It represents a volume of the engine bay out of the mainstream of nacelle ventilation and in a sense was isolated. This could tend to inhibit the flow of extinguishing agent into this space unless one leg of the bifurcated extinguishing nozzle is oriented directly into this area. The extinguishing nozzle is not keyed but Technical.Orders specify an angle of orientation. As the ventilation rate increases the volume of this swirling air mass appears to enlarge as noted earlier. It is, therefore, possible that the extinguishing system could become less effective in this area with increasing airspeed. Furthermore, flammables collecting in this area would not readily be vented or if ignition occured, would inhibit the fire from being blown out the rear as the design was so intended.

Figure 22 is a sketch depicting an approximation of flow patterns, with the flapper doors installed, based on video and motion picture data. The fuselage station identification at the bottom of the figure is for reference only and should not be used in precisely locating flow patterns. This figure is for general reference only. The solid arrows represent flow along the inner nacelle wall and the dashed arrows represent flow near the engine case and accessories. The drawing at the top of this figure is an approximation of what occurs within the observable engine bay at a ventilation rate of 7 lb/sec; and the lower drawing at 22 lb/sec. Generally, there was little difference between the overall flow pattern at the two ventilation rates. The tufts near the bottom of the engine at FS 595 are oriented somewhat differently between the two flow rates but nevertheless still indicate a reverse flow. The tufts near the top of the engine at approximately the same fuselage station are horizontal at 22 lb/sec but angled slightly downward at 7 lb/sec. This slight difference could be attributed to the higher inertia of the incoming air at the higher ventilation rate whereas at the lower ventilation rate the path of the incoming air was more suseptible to the influence of the theorized low pressure area at the bottom of the engine.

To summarize, the airflow patterns with the flapper doors installed was virtually fore-to-aft at the nacelle wall for most of the length of the engine bay. The major exception is the area of reverse or circulatory motion of the air under the engine just aft of the vertical firewall. Flow near the engine case can vary significantly when compared to that at the nacelle wall at the same fuselage station. There was no significant differences in airflow patterns between the low (7 lb/sec) and high (22 lb/sec) ventilation rates.

DISCUSSION OF TEST RESULTS (FLAPPER DOORS REMOVED)

As noted previously, the removal of the flapper doors resulted in no significant change in overall or local airflow patterns as compared to that with the flapper doors installed. With the introduction of CO_2 at the 3 o'clock position and a ventilation rate of 7 lb/sec, the same single wave pattern was apparent but was not as pronounced as that with the flapper doors installed. It also peaked slightly farther downstream at approximately FS 680. Since this characteristic pattern occurs with or without the flapper doors, the presence of the doors are not the primary cause of this motion. Rather, it is surmised to be largely due to the influence of the reverse flow area at the bottom of the engine just aft of the aerodynamic firewall. It has been hypothesized that this is an area of lower pressure and which influences the direction of flow of the air entering through the firewall. The flapper doors presumably have some effect, also, in changing the direction of flow, at least briefly, since the doors do not open fully and are hinged at an angle. The doors would tend to deflect the incoming air downward and therefore, may contribute to the CO_2 wave peaking slightly more upstream. Conversly, the absence of the flapper doors permit the air to enter without being deflected by the doors and thus travels further downstream before being influenced by the surmised low pressure area under the forward part of the engine. This could contribute to the CO_2 wave pattern peaking further downstream. Nevertheless, the single wave-like pattern exists with or without flapper doors at the 7 lb/sec ventilation rate. In figure 23, CO_2 is passing through the engine bay and the ventilation rate is 7 lb/sec. The wave pattern is not discernible in a still photograph but this particular figure is used to illustrate another point. The haziness noted through the windows along the side of the fuselage shown in this figure is evidence of the presence of CO_2 in the airstream. Note the clarity through the windows shown in the reflecting surface under the fuselage. Had there been a continuous helical flow pattern, the CO_2 would have been visible through the windows under the fuselage. Although this figure shows a test in progress with the test article less the flapper doors, the CO_2 behavior is the same without flapper doors. Some of the following discussion will note the similarities in airflow patterns between that without flapper and that previously described with flapper doors.

The introduction of CO_2 at the 22 lb/sec does not display the wave-like motion as it passes through the engine bay as it did during the 7 lb/sec ventilation rate. The recorded media indicated a virtual horizontal flow. As noted previously, it is possible that at the higher airspeeds within the engine bay, this wave-like pattern either does not exist or more likely, is not discernible with the techniques used. The behavior of the CO_2 flow pattern was very much alike when comparing like ventilation rates, with or without flapper doors.

As noted in those tests described with flapper doors in place, tuft orientation provided a greater insight regarding airflow pattern than did the CO_2. Figures 24 and 25 are overall views of the F-111 test article with the reflecting surface located under the fuselage. In figure 24 the ventilation rate was 7 lb/sec and in figure 25, 22 lb/sec. Because of the distance at which these photos were taken, tuft orientation is not obvious in all cases. Under the fuselage aft of FS 670 all tufts are oriented fore-to-aft for both the high and low ventilation rates. The tufts along the outboard side are, also, aligned similarly for both flow rates, although there is a difference between the orientation of the tufts on the inner nacelle wall and engine case. Figures 26 and 27 are closer views of the outboard portion of the test article between FS 655 and FS 720: figure 26 showing tuft orientation at an engine bay ventilation rate of 7 lb/sec and figure 27 at 22 lb/sec. Note that there is no significant difference between these two figures. Note, also, the similarity between figures 26 and 27 and those showing tuft orientation with flapper doors in figures 14 and 15. These four figures, 14, 15, 26, and 27 illustrate the similarity in flow pattern, with and without flapper doors at both the high and low ventilation rates.

Figures 28 and 29 show tuft orientation in the afterburner section between FS 730 and FS 760: figure 28 illustrating ~~what~~ that which occurred at 7 lb/sec and figure 29 at 22 lb/sec. Note the similarity between these two figures and figures 16 and 17 which are views through the same windows when testing with flapper doors. Figures 30 and 31 show an area through the windows under the test article at the same fuselage location (i.e., FS 730/760). Observe the horizontal orientation of the tufts both on the afterburner case and nacelle wall, an indication that the air is exiting straight aft. Refer to figures 18 and 19 which are views through the same windows with the flapper doors installed and note the similarity to figures 30 and 31. The latter two photographs were taken of the reflecting surface.

Figures 32 and 33 are views through windows under the fuselage between FS 670 an FS 720 and were taken of the reflecting surface. Refer to figures 24 and 25 for the precise location of these windows with reference to the fuselage. The closer view shows the fore-to-aft flow indicated by the tufts in both figures 32 and 33, the former at 7 lb/sec and the latter at 22 lb/sec.

Figure 34 is a close-up view of the aft outboard engine mount. This figure shows more clearly what was noted previously in describing the tests with the flapper doors installed. Forward of this mount, which is to the right in this figure, shows the tufts oriented vertically downward on the engine case; and vertically upward aft of the mount. The tufts on the viewing window, which would represent flow along the inner nacelle wall are oriented aft at right angles to the flow on the engine case. This flow pattern was characteristic at both the high and low ventilation rates and whether the flapper doors were installed or removed.

Perhaps the most significant area of the observable engine bay, again, was the area below the engine just aft of the aerodynamic firewall. Figures 35 and 36 show a view through the window slightly downstream of the firewall (right side of figure) and also show a view through windows further aft. These views were taken of the reflecting surface. The top portion of the figures, therefore, is the bottom of the fuselage and the lower portion of the figures shows a portion of the side of the fuselage. The entire view in these figures show an area between approximately FS 595 and FS 640. The space aft of the aerodynamic firewall displays the same general airflow characteristics as that with the flapper doors installed. The window to the right in figures 35 and 36 is the same as that shown in figures 20 and 21, except that in the latter two the flapper doors are installed. At a ventilation rate of 7 lb/sec, without flapper doors, the tufts below the engine at FS 595 indicated virtually no flow and almost a total absence of any air circulation along the nacelle wall.

In figure 35, which is a view from the bottom, the tufts shown on the window at the right were motionless and have merely assumed a random position while resting on the window. The tufts secured to the inner components and engine case in the same general area, dangled vertically downward with an occasional lazy movement as if in a gentle breeze. Tufts secured to components and engine case further up (toward the 5 o'clock position) displayed slightly more movement but still dangled vertically. The airflow or circulation was not vigorous enough to orient the tufts to any direction except the vertical. This did not suggest a vertical movement of air, but because of an almost total lack of tuft movement, this space can more accurately be described as a "dead" airspace. The total lack of movement of tufts resting on the bottom of the window tends to support this hypothesis. The tufts secured to the viewing windows and engine accessories further aft in figure 35 (7 lb/sec) are not motionless and in fact indicate a flow toward the outboard side, upward and aft. The small circular window and adjacent small rectangular window show tufts oriented outboard and aft. This suggests a flow counter clockwise in this portion of the nacelle, opposite that proposed by General Dynamics. However, this pattern was not maintained and was somewhat local. The flow eventually was aligned fore-to-aft under the engine further downstream. This same pattern also occurred when flapper doors were installed. Figures 37 and 38 are close-up views of the larger window shown on the left in figures 35 and 36. In figure 37, which shows tuft orientation at a ventilation rate of 7 lb/sec, the tufts near the bottom are oriented slightly upward and aft. Note that the view in this figure is directly through the window and shows more of the side of the fuselage than in figure 35, which shows more of the bottom of the fuselage.

At a ventilation rate of 22 lb/sec there was much more tuft movement in the area below the engine aft of the firewall and no longer displayed the characteristics of a "dead" airspace. The tufts on the inner nacelle wall and accessories assumed a forward direction, i.e., opposite that of the main air stream. Figure 36 shows the window just downstream (right side of figure) of the firewall and is partially obscured by the reflector frame and most tufts cannot be seen. For this particular test condition, the CO_2 was pulsed several times and its behavior in this area noted. Recall that the CO_2 was introduced parallel to the incoming air stream at the 3 o'clock position. The CO_2 was observed to enter the area of the lower firewall from above and flow forward. Since the zone adjacent to and immediately aft of the firewall could not be seen, a further trace of the CO_2 path could not be made. This does further corroborate, however, a forward airflow in this zone. The tufts that can be seen through the window further aft (middle of figure) show a flow pattern that is like that which occured at 7 lb/sec (figure 35). Flow is toward the outboard side, upward and aft. Figure 38 is a closer view of the larger window that is shown in the middle of figure 36. Note that the tufts in the lower portion of this figure (near bottom of fuselage) are oriented upward and aft. The overall tuft orientation in this area suggests that the air entering through the firewall was induced to flow downward by the hypothesized low pressure area under the forward portion of the engine. As it impinges on the lower nacelle wall, a portion is deflected upward and aft and is evident in figure 38.

In order to better characterize this local aberrant air circulation behavior, a video recording was made through the viewing window at FS 595. Ventilation rate was varied from near zero to 22 lb/sec. At the lowest flow rate (approximately 2.5 lb/sec) there was little or no movement of any tuft and all were dangling under their own weight or rested motionless on that portion of the Lexan window that curled under the fuselage. As the flow rate was increased, some movement was noted on those tufts that were hanging but there was not enough air movement to orient them in any particular direction. The tufts secured to the viewing window on the bottom remained motionless. As the airflow was increased further, the tufts secured to the engine case and accessories continued to oscillate but, also, became more oriented forward as did those secured to the window that were previously motionless. Increasing the airflow yet further toward a maximum of 22 lb/sec, all tufts assumed a forward facing direction. There was no ventilation rate, with or without flapper doors when the space below the engine aft of the aerodynamic firewall between FS 595 and FS 610 did not exhibit the characteristics of apparent reverse flow; or a "dead" airspace which occured at a ventilation rate of 7 lb/sec with flapper doors. Ref p 24A,B

Figure 39 is similar to figure 22 in that it is a sketch approximating airflow patterns within the engine by using tuft orientation as noted on the visual recorded media. Figure 39 is a representation of that which occurs without flapper doors at both the low and high ventilation rates. The solid arrows indicate flow along the nacelle wall and the dashed arrows along the engine case. The cross-hatched area in the upper sketch is the "dead" area described previously.

Figure 40 is a sketch representing airflow patterns as viewed through the windows on the underside of the fuselage. For both the high and low ventilation rates the flow was virtually fore-to-aft in the rear portion of the engine bay. Somewhat aft of the vertical firewall at about FS 630 the flow was outboard. The cross-hatched area in the top sketch (7lb/sec) indicates an area of relatively little tuft movement and can be characterized as a near "dead" air space. The extent of the volume occupied by this space of little or no tuft movement is not known and hence the cross-hatched area represents only that portion of the engine bay that was observable. No attempt was made to interpolate. No comparable sketch is presented for the test condition with flapper doors since for both the high and low ventilation rates, the bottom sketch of figure 40 closely approximates this test condition.

Page 16 replace last para with the following or place on page 24 after 2nd para

This aberrant air flow behavior that occurs adjacent to the lower portion of the aerodynamic firewall presents some matters of concern. It represents a volume of the engine bay out of the mainstream of nacelle ventilation and in a sense, isolated. A fire initiated in this area may not proceed rearward in the expected or designed manner and hence may be confined by the circulating air flow pattern. This flow pattern could, also, provide favorable conditions for fuel puddling and inhibit its free flow out the rear or toward a nacelle drain. Fuel puddling with a constrained circulatory pattern of air presents a potentially catastrophic situation. On the positive side, the apparent circulatory air flow pattern could enhance fire extinguishment [illegible] a small fire if the fire extinguishing system allows sufficient entry of extinguishant into this area. The extinguishing agent nozzle is not keyed but Technical Orders specify an angle of orientation which presumably is intended to allow one leg of the bifurcated nozzle to direct agent into this area.

The F-111 has only one fire bottle and if the fire is not extinguished or if it is extinguished and re-ignites, this apparent isolated portion of the nacelle could present a matter of concern.

An agent concentration study should include a thorough probing of this area to determine the effectiveness of agent distribution. Additionally, since flapper doors have been removed from F-111's currently in the fleet, a probing of the plenum forward of the aerodynamic firewall should be done to ascertain if there is truly reverse flow, ie. ventilating air re-entering the plenum. Although these tests could not verify or negate this possibility of air re-entering the plenum, if such a condition exists the results could be catastrophic since this is an unprotected area. A reverse flow condition could, also, entrain agent and carry it into the plenum and could offer some protection if there is sufficient concentration. In any case, these tests have not only provided some insight into engine bay air flow patterns, but these same air flow patterns have suggested the possibility of potentially damaging situations

Figure 41 was derived from figure 39 (22 lb/sec ventilation rate) and was an attempt to depict an overall flow picture. To the right in this figure is shown how the incoming air stream might be divided as it impinges onto the lower nacelle wall with a portion reversing it direction; and a portion being deflected upward and aft. From the data available in conducting this test program, figure 40 could closely represent the flow picture with or without flapper doors and at either the high or low ventilation rates. It is important to note that only a small portion of the engine bay was observable. Undoubtedly, the flow through the hidden areas of the engine bay had an effect on the flow through the observable engine bay. An evaluation of the interaction of these cannot be made with certainty.

CONCLUDING STATEMENT.

Complicated airflow patterns exist within the F-111 engine bay. However, there is no evidence that a complete helical pattern exists at either a ventilation rate of 7 lb/sec or 22 lb/sec, and whether the flapper doors were installed or removed. There are areas where airflow along the inner nacelle wall varies from that along the engine case at the same fuselage station. Along the engine case between approximately FS 650 and 700, the airflow is angled downward and aft, whereas, along the inner nacelle wall the flow is virtually fore-to-aft. At FS 595, below the engine there exists a reverse flow pattern which appears to be part of a circulatory motion of air in this area.

See p 30

Generic Applications

This test program centered about a particular aircraft and whose tests were limited due to the configuration of the aircraft test article. Therefore, generic applications of the findings are limited and general in nature.

Perhaps one of the most significant of the generic applications involves the theory that air flow can be of sufficient velocity to cause an engine compartment fire to be blown aft and out the rear of the aircraft. The supposition is that the velocity of the ventilating air is higher than the flame propagation rate of a hydrocarbon fuel and thus the fire never establishes a foothold. Although no engine compartment fires were planned nor conducted as part of the air flow visualization test program, small fires (1 gph) were initiated within the engine bay during preliminary tests of another test program. These preliminary tests were conducted subsequent to the completion of the effort described in this report. It is relevant to present the consequence of one of these tests [illegible] significant [illegible] argument that a practical approach must be incorporated to allow the high velocity air flow theory to render the desired results. As part of the aforementioned test program, a fire (Jet A fuel) was initiated using a one gph fuel nozzle and a spark igniter. The ventilating air was of sufficient velocity at the nozzle location to blow out the fire at the nozzle. The fuel-to-fire was allowed to continue uninterrupted for a period of time. Video and personal on-site observation had shown that the fire had attached itself to a wire bundle about one foot downstream of the nozzle. The significance of this phenomenon was that high local air velocity precluded flame retention at the nozzle yet found a suitable location downstream where the localized environment was suitable for the flame to be sustained. The flame was maintained until the fuel was shut off. It is important again to emphasize that this test was not part of the airflow visualization studies nor was it designed to locate potential "flame holders" inherent in the F-111 engine bay. What had occurred was coincidental, but worthy of note.

An engine compartment design incorporating the concept of ventilating air exceeding flame propagation rate must be tempered with pragmatism. Flame propagation rates are a function of fuel/air ratio and droplet size. Other factors such as the percent of vaporized fuel and fuel temperature are related to fuel/air ratio. Hakimson and Eklund (Ref 2) report flame speeds through fuel mists of kerosene and JP-4. For JP-4 flame speed is reported to be a maximum of about 16 fps as a result of their tests; for kerosene the maximum exceeds 40 fps. McClure and Springer (Ref 1) depict a velocity distribution through the F-111 engine bay at various aircraft operating conditions. At a ground run condition, the lowest local air velocity, at fuselage station (FS) 700, is about 6.4 fps. At the same FS, but at aft. Within a relatively small volume of the nacelle, air velocity vectors were shown to be vertically upward, vertically downward and horizontally aft. Predicting an internal nacelle air flow pattern and assuming that at any point within the nacelle the air velocity vector is directed aft was shown to have some misgivings. The results of this test program did not substantiate the assumptions and predictions made in Ref. 1. At FS 595 just aft of the aerodynamic firewall at the bottom of the nacelle another unusual air flow pattern was evident. This area, discussed previously in this report, was shown to have manifestations of reverse flow. Among other things, this report attempts to point out that for any engine/nacelle design, incorporating the concepts of unidirectional air flow and velocity exceeding that of flame propagation rate must be approached with caution. The fact that it was ascertained that in some locations within the nacelle, air velocity vectors were directed in a [illegible] or forward direction casts some doubt as to whether some fires could be blown out the rear. Perhaps the unidirectional flow of air concept could be enhanced by introducing the air into the annulus around the engine in a 360° pattern.

CONCLUDING STATEMENT

Complicated airflow patterns existed within the F-111 engine bay. However, there was no evidence that a complete helical pattern existed at either a ventilation rate of 7 Lb/sec or 22 Lb/sec, and whether the flapper doors were installed or removed. There were areas where airflow along the inner nacelle wall varied from that along the engine case at the same fuselage station. There were, also, areas whose air flow patterns manifested indications of reverse flow.

Engine/nacelle installations vary among different aircraft and further, engine/nacelle installations may vary among different models of the same aircraft. Hence it is difficult to propound generic applications. Generic considerations can, however, take the form of cautions and were so noted where deemed applicable.

CONCLUSIONS

1. No continuous helical airflow pattern exists within the F-111 engine bay at either 7 lb/sec or 22 lb/sec nacelle ventilation rates, whether the flapper doors are installed or removed.

2. A reverse airflow condition exists below the TF-30 engine aft of the aerodynamic firewall at approximately FS 595.

3. No significant changes occur in either local or overall airflow patterns within the F-111 engine bay when flapper doors are removed at either the low (7 lb/sec) or high (22 lb/sec) nacelle ventilation rates.

4. Airflow below the engine aft of FS 670 is parallel to the engine in a virtual fore-to-aft direction.

5. Airflow adjacent to the engine case can vary significantly with that along the inner nacelle wall.

6. The passage of CO_2, when introduced behind the aerodynamic firewall parallel to the incoming air at the 3 o'clock position, takes on the characteristics of a single-wave pattern along the observable outboard side at a ventilation rate of 7 lb/sec with the flapper doors installed and removed.

7. The wave-like pattern noted in item 6 is not discernible at a ventilation rate of 22 lb/sec, whether the flapper doors are installed or removed.

RECOMMENDATIONS

1. During agent concentration studies, the space under the fuselage between FS 593 and FS 650 should be probed thoroughly to assure adequate fire protection.

2. During agent concentration studies, the space within the plenum should be probed thoroughly, particularly without flapper doors, to ascertain whether the reverse airflow condition results in air re-entering the plenum.

REFERENCES

1) McClure, J.D., Springer, R.J., Environmental and Operating Requirements for Fire Extinguishing Systems on Advanced Aircraft, Report No. JTCG/AS-74-T-002, Nov. 1974 (USAF Report No. AFAPL-TR-73-122)

2) Atkinson, A.J, Eklund, T.I., Crash Fire Hazard Evaluation of Jet Fuels, Report No. FAA-RD-70-72, Jun. 1971.

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APPENDIX

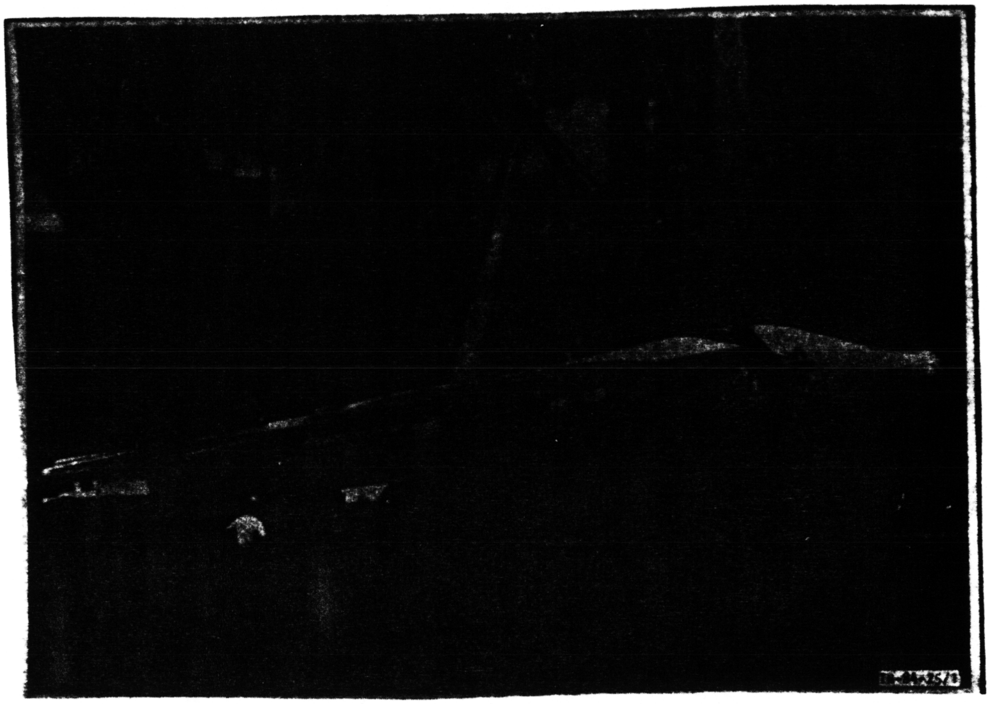

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FIGURE 1. OFF LOADING OF THE F-111 FUSELAGE AT THE MILITARY OCEAN TERMINAL

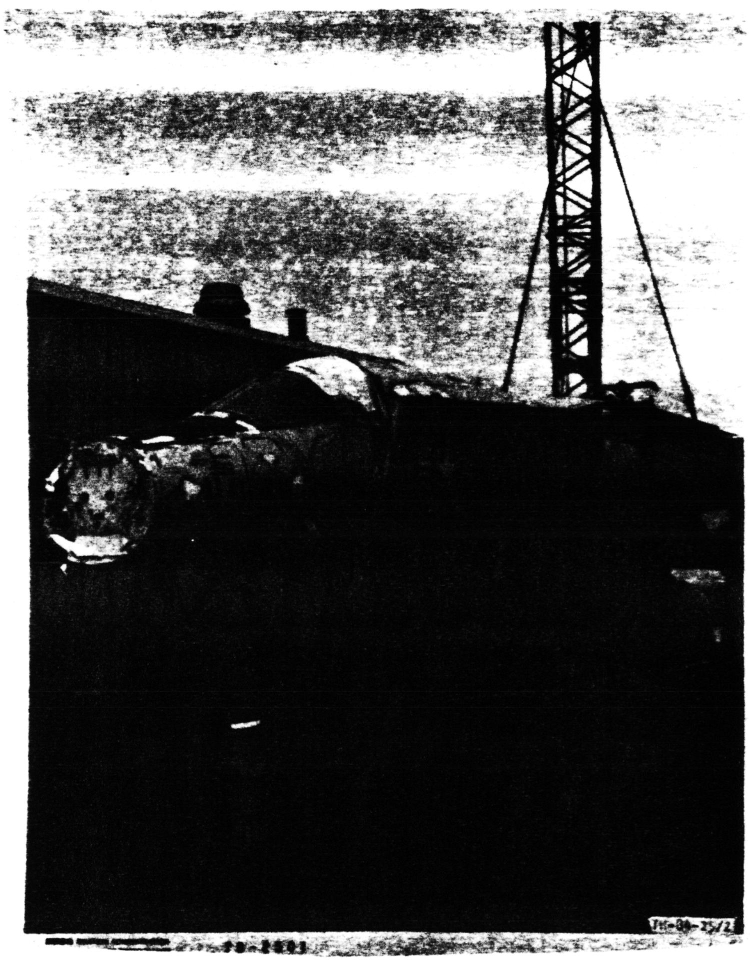

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FIGURE 2. BEING FITTED WITH "MAIN GEAR"

FIGURE 3. F-111 "MAIN GEAR" SHOWING DC-3 WHEELS

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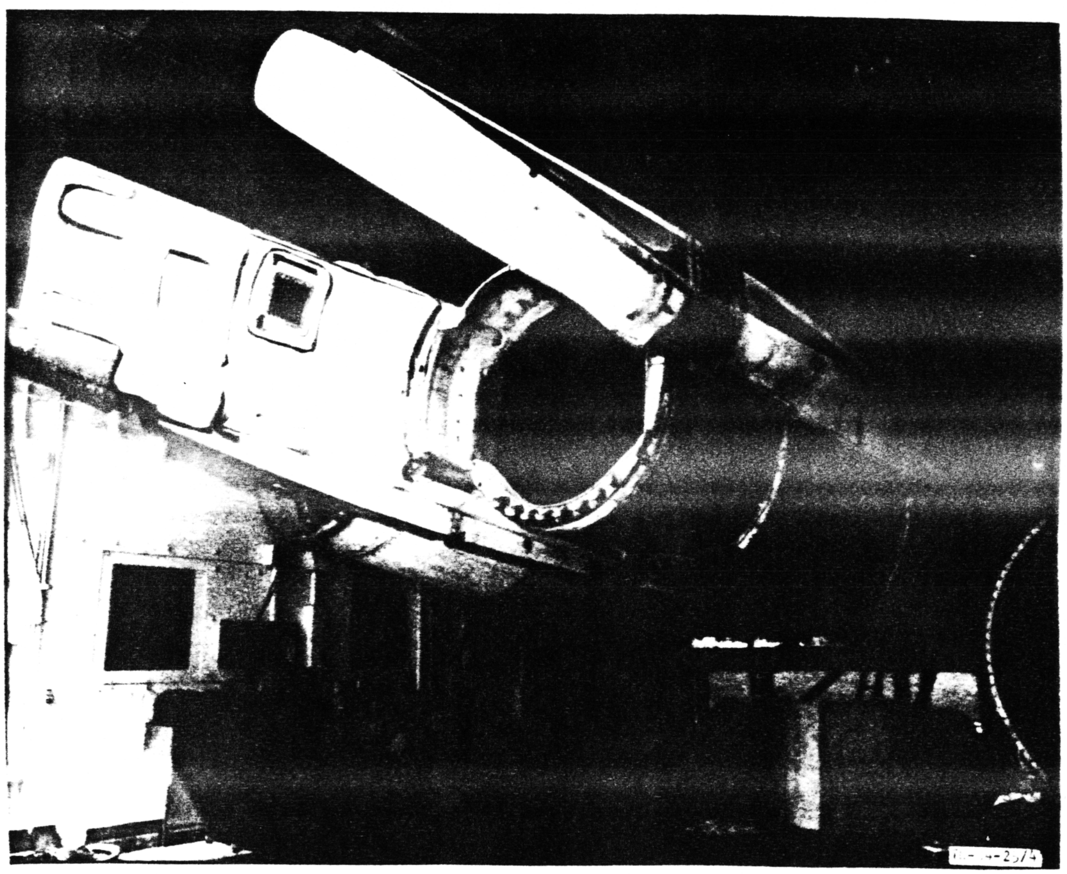

FIGURE 4. F-111 RIGHT-HAND ENGINE BAY LESS ENGINE AND MACELLE DOORS

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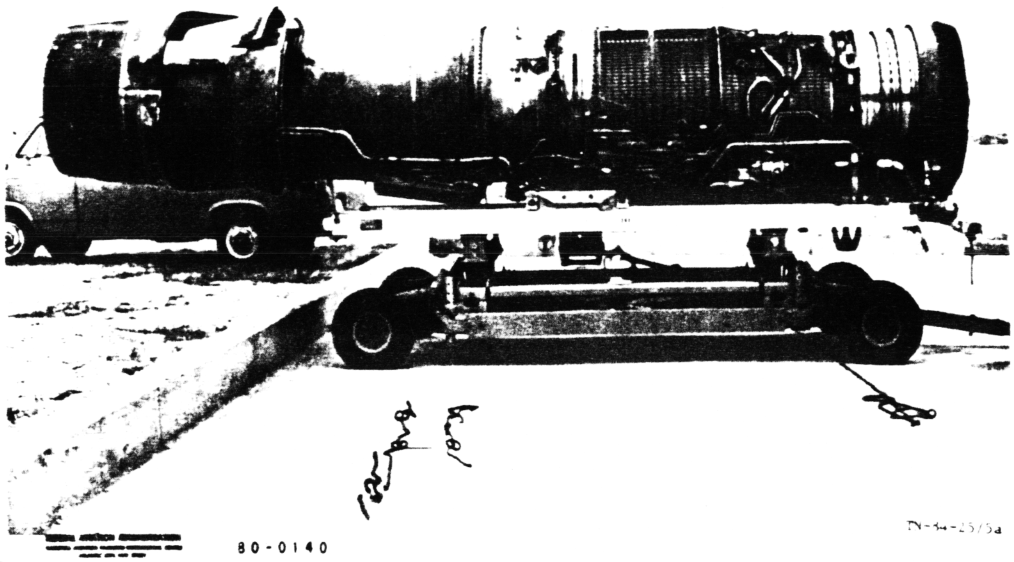
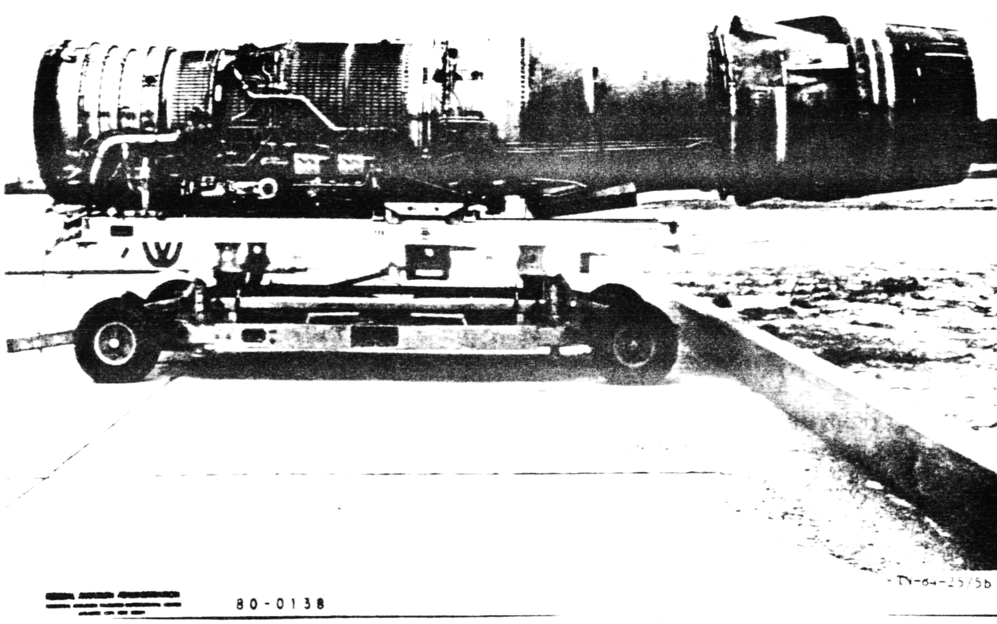


(a)



(b)

FIGURE 5. TF-30 MOUNTED ON INSTALLATION DOLLY

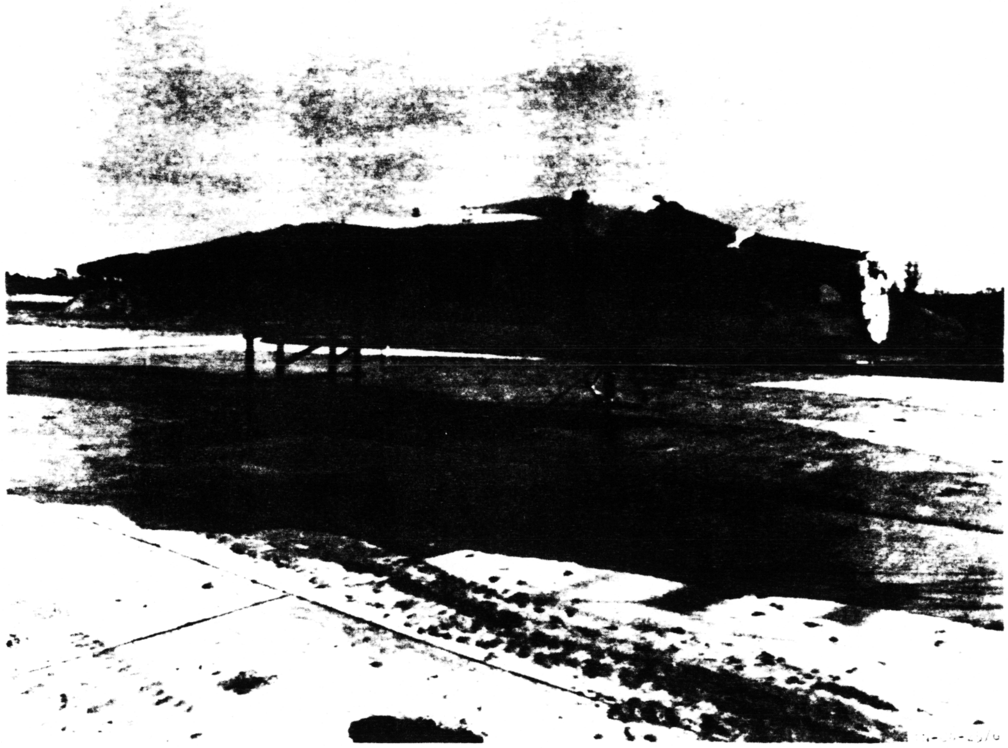


FIGURE 6. F-111 SECURED TO TEST PAD

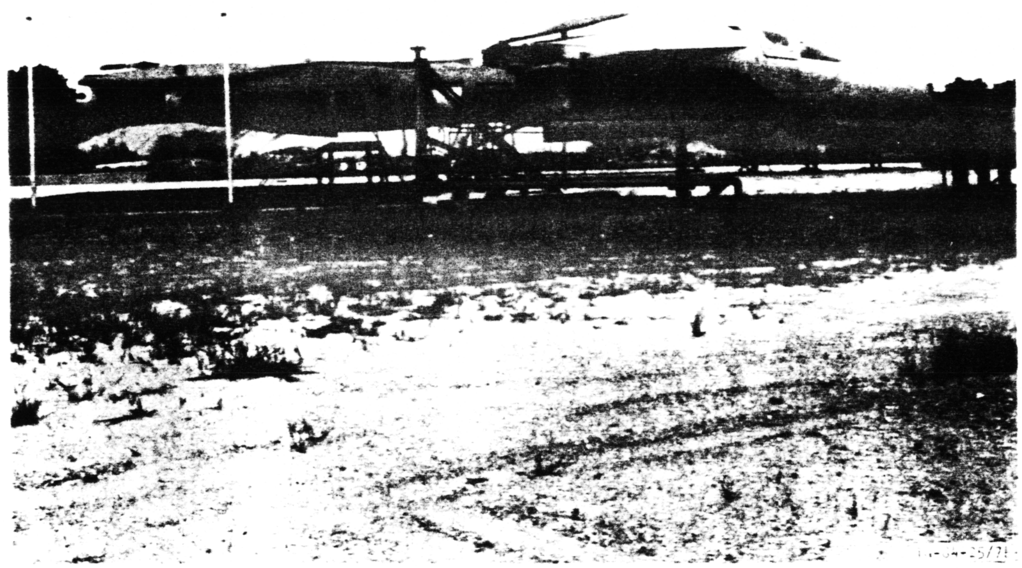


FIGURE 7. F-111 WITH VENTILATING AIR SUPPLY DUCT AND VIEWING WINDOWS INSTALLED

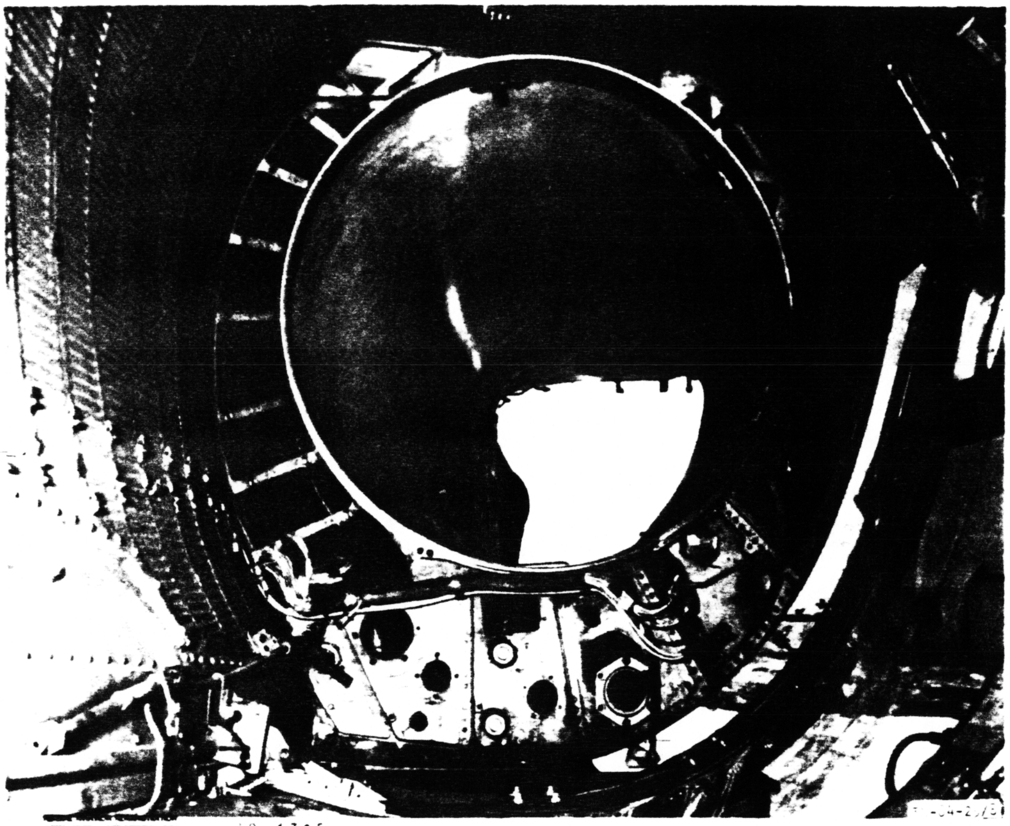


FIGURE 8. RIGHT-HAND ENGINE BAY (LOOKING FWD) WITH FLAPPER DOORS REMOVED

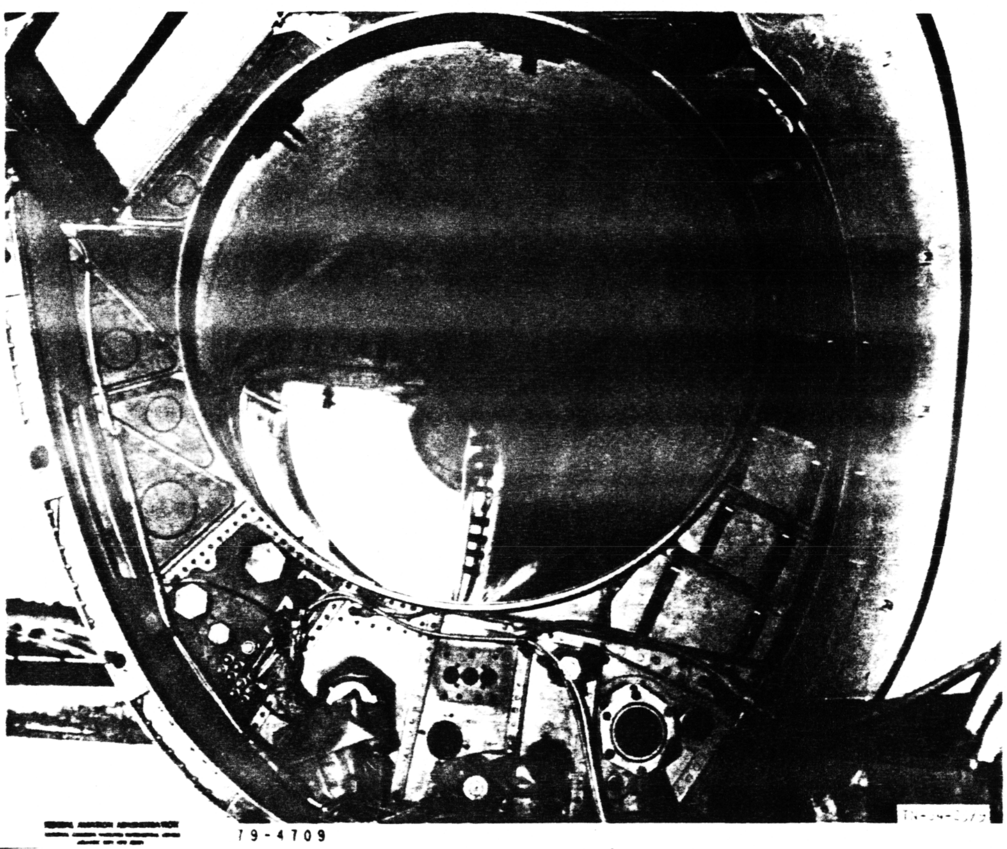


FIGURE 9. LEFT-HAND ENGINE BAY (LOOKING FWD) WITH FLAPPER DOORS INSTALLED

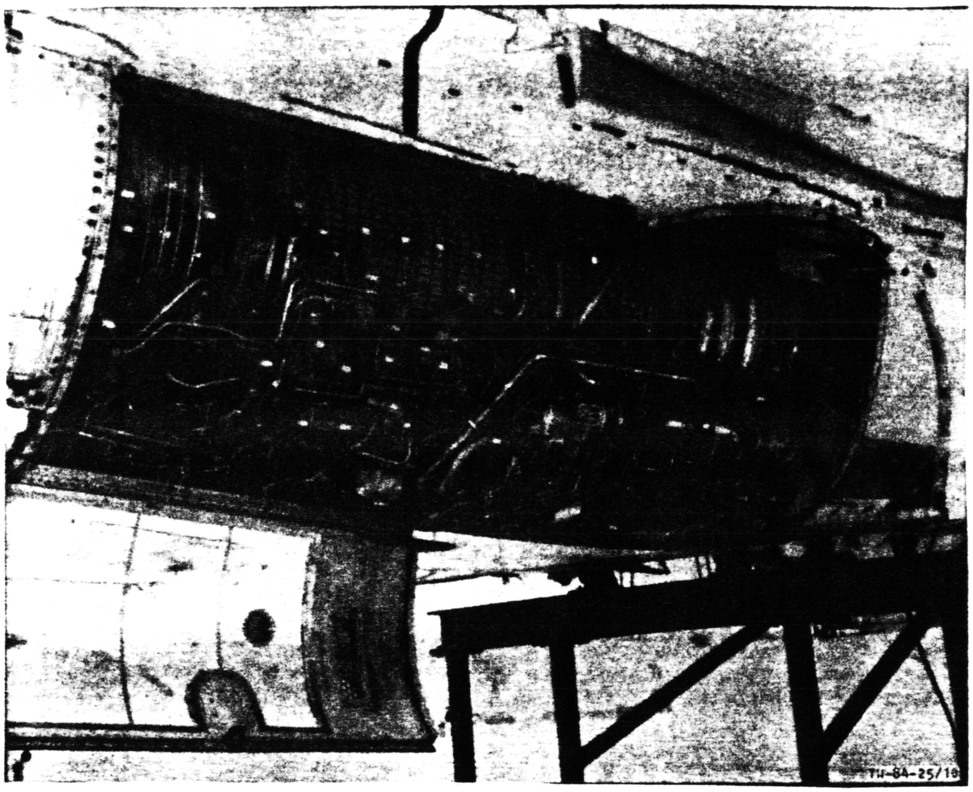


FIGURE 10. TF-30 ENGINE INSTALLATION SHOWING TUFTS

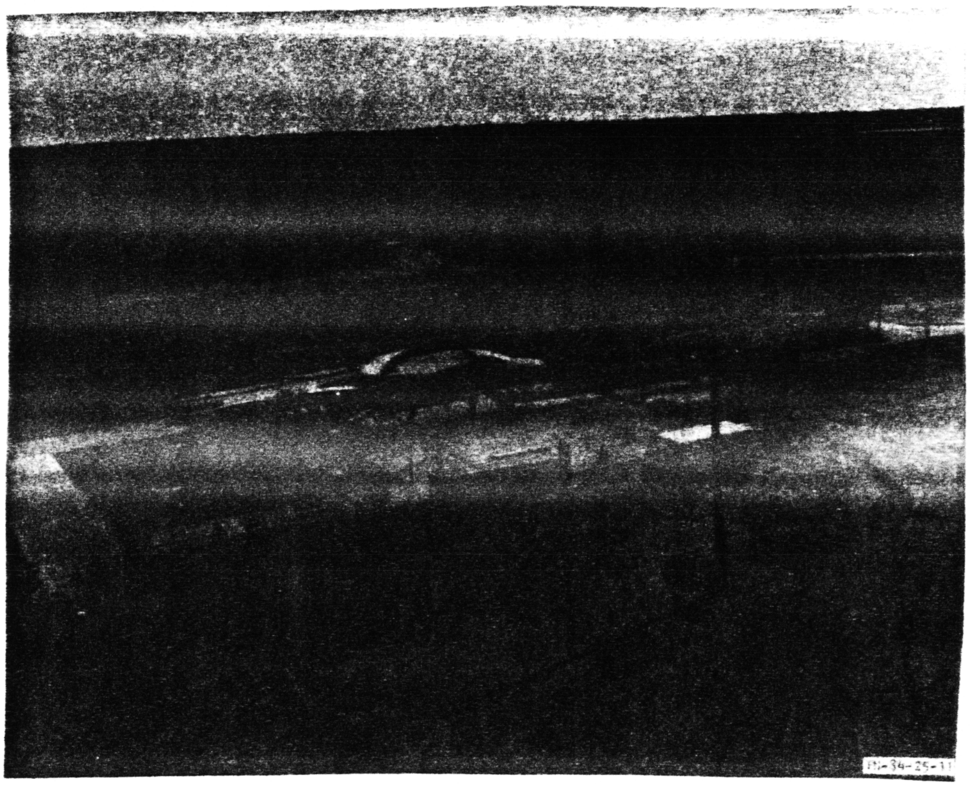


FIGURE 11. AIRFLOW FACILITY SHOWING TEST ARTICLE INSTALLATION

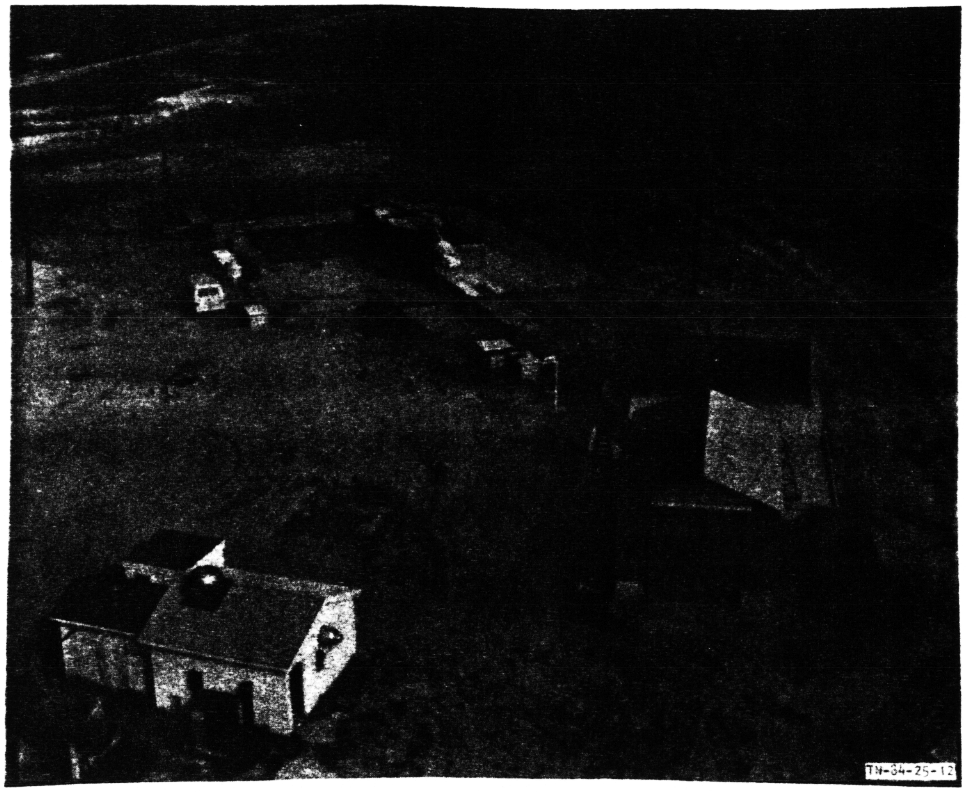


FIGURE 12. AIRFLOW FACILITY SHOWING TEST ARTICLE INSTALLATION AND YTF-33 ENGINE ENCLOSURE

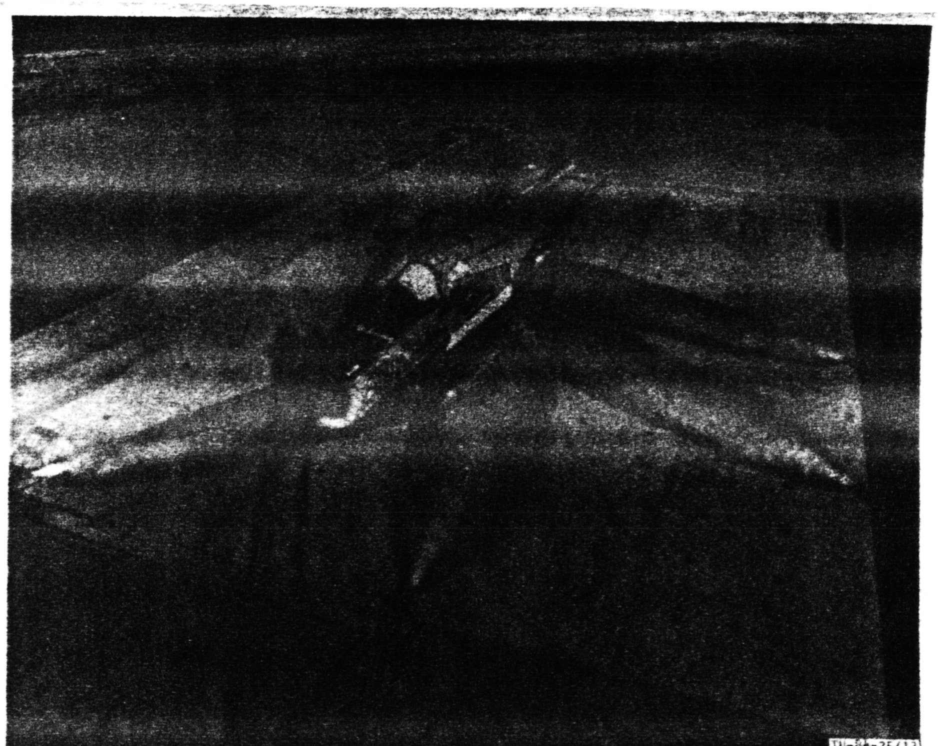


FIGURE 13. WATER DELUGE SYSTEM IN OPERATION

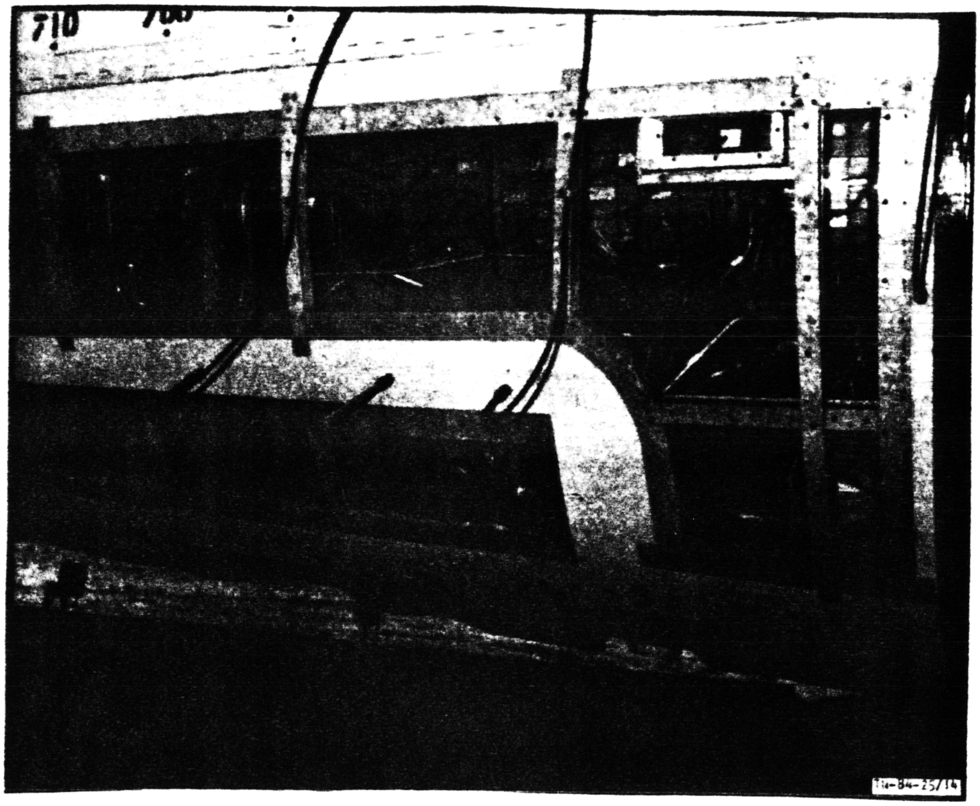


FIGURE 14. TUFT ORIENTATION BETWEEN FS655/720 (SIDE) WITH FLAPPER DOORS — VENT. RATE 7 LBS (SIDE)

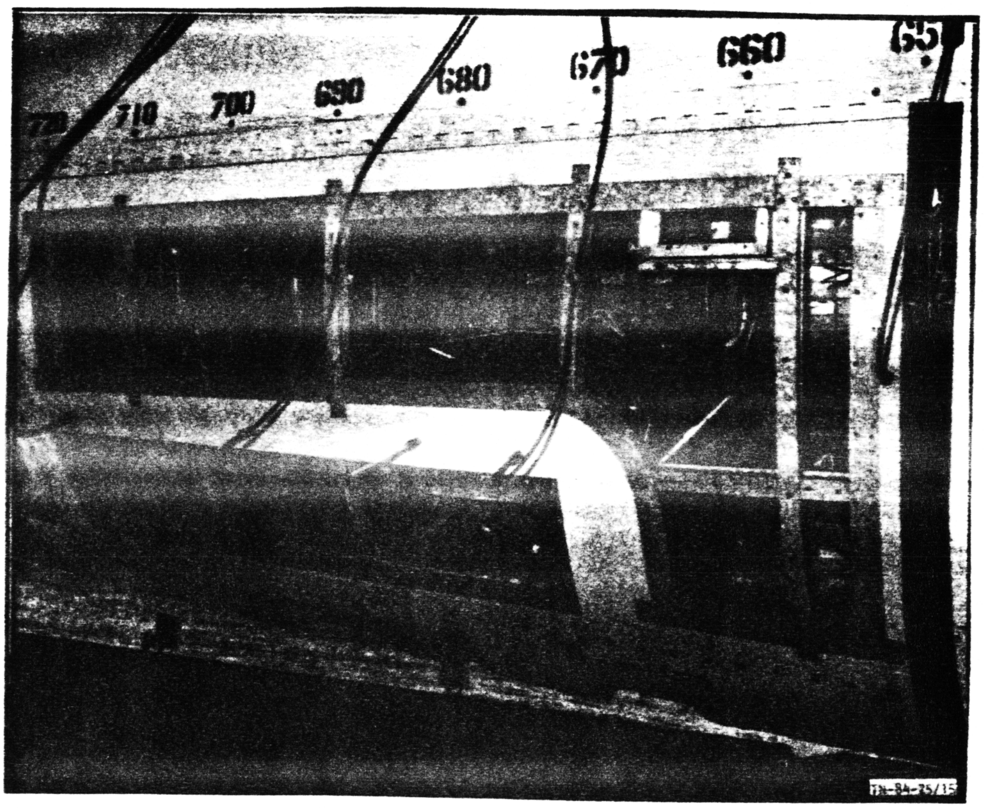


FIGURE 15. TUFT ORIENTATION BETWEEN FA 655/720 (SIDE) WITH FLAPPER DOORS — VENT. RATE 22 LBS/SEC.

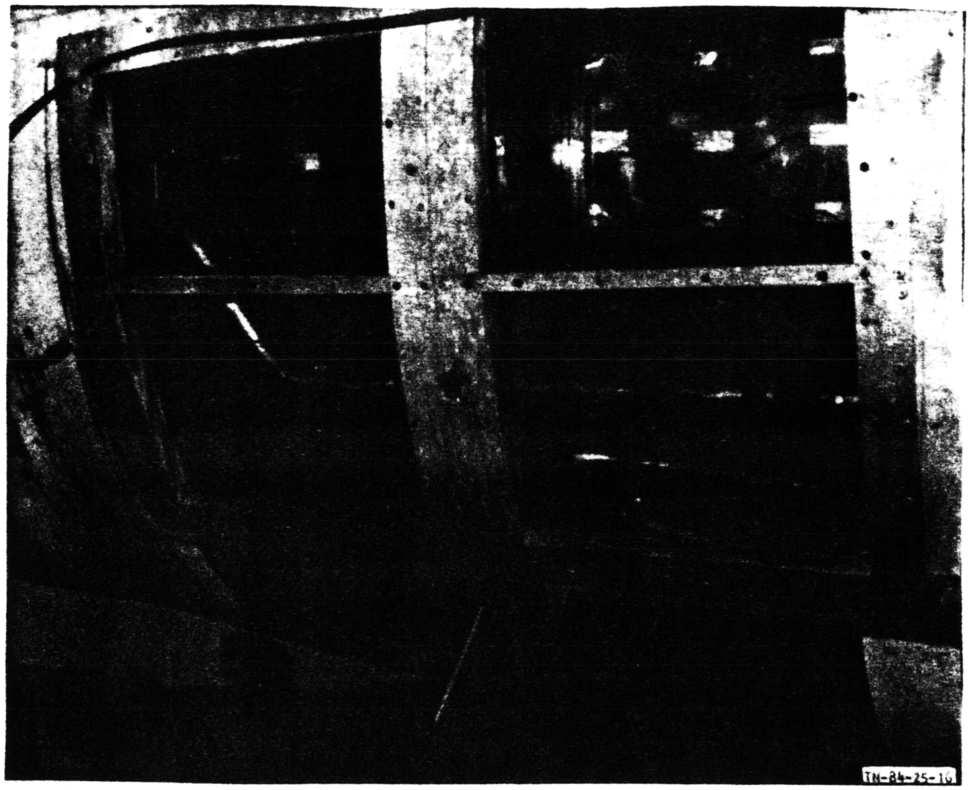


FIGURE 16. TUFT ORIENTATION BETWEEN FS 730/760 (SIDE) WITH FLAPPER DOORS — VENT. RATE 7 LB/SEC.

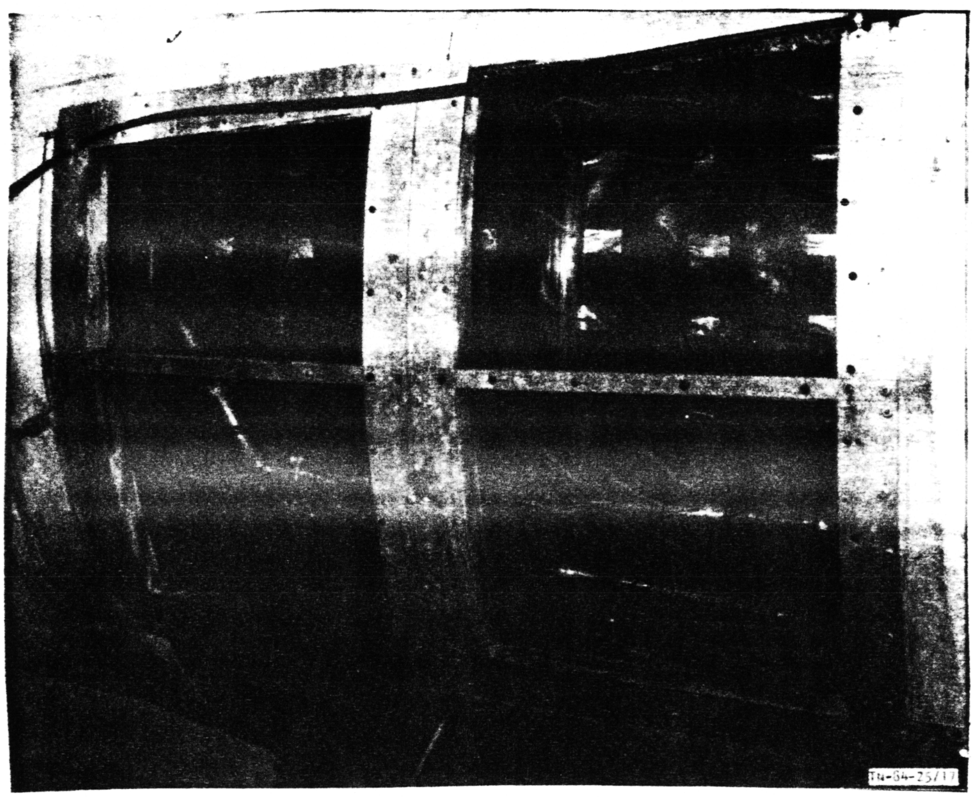


FIGURE 17. TUFT ORIENTATION BETWEEN FS 730/760 (SIDE) WITH FLAPPER DOORS — VENT. RATE 22 LB/SEC.

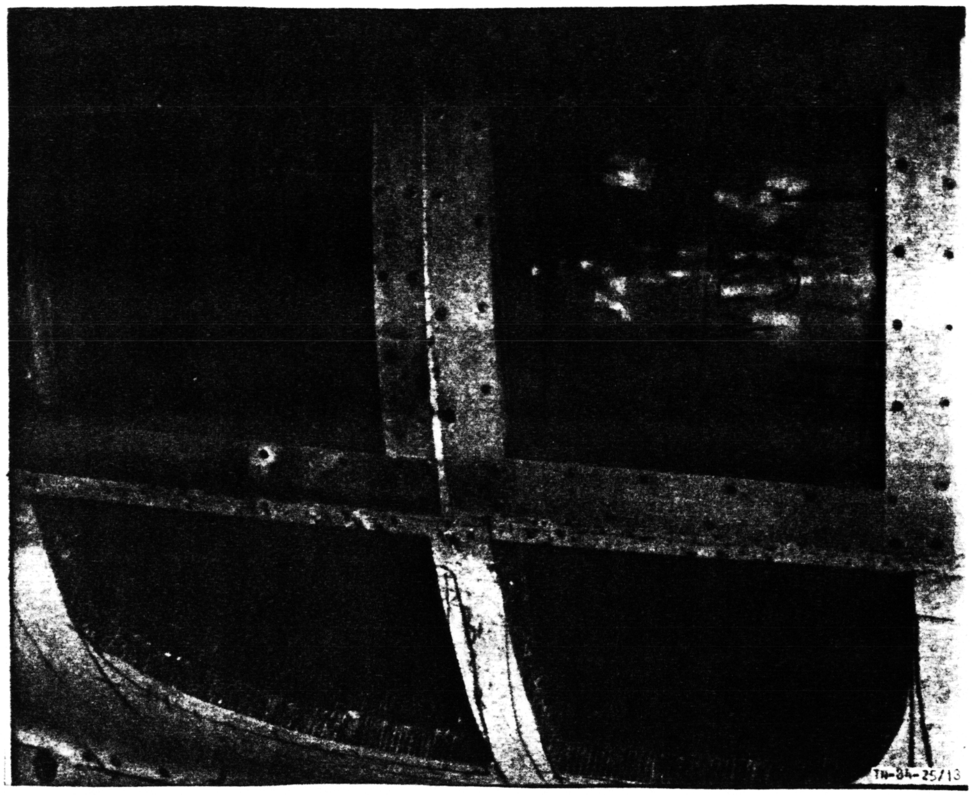


FIGURE 18. TUFT ORIENTATION BETWEEN FS 730/760 (BOTTOM) WITH FLAPPER DOORS — VENT. RATE 7 LB/SEC.

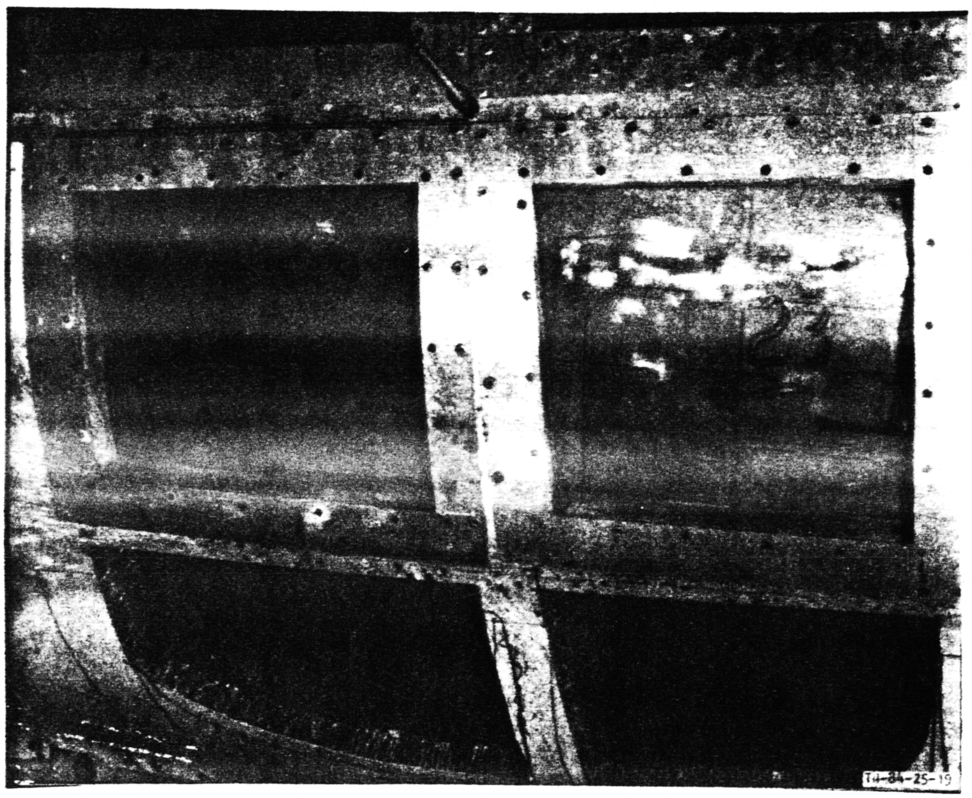


FIGURE 19. TUFT ORIENTATION BETWEEN FS 730/760 (BOTTOM) WITH FLAPPER DOORS — VENT. RATE 22 LB/SEC.

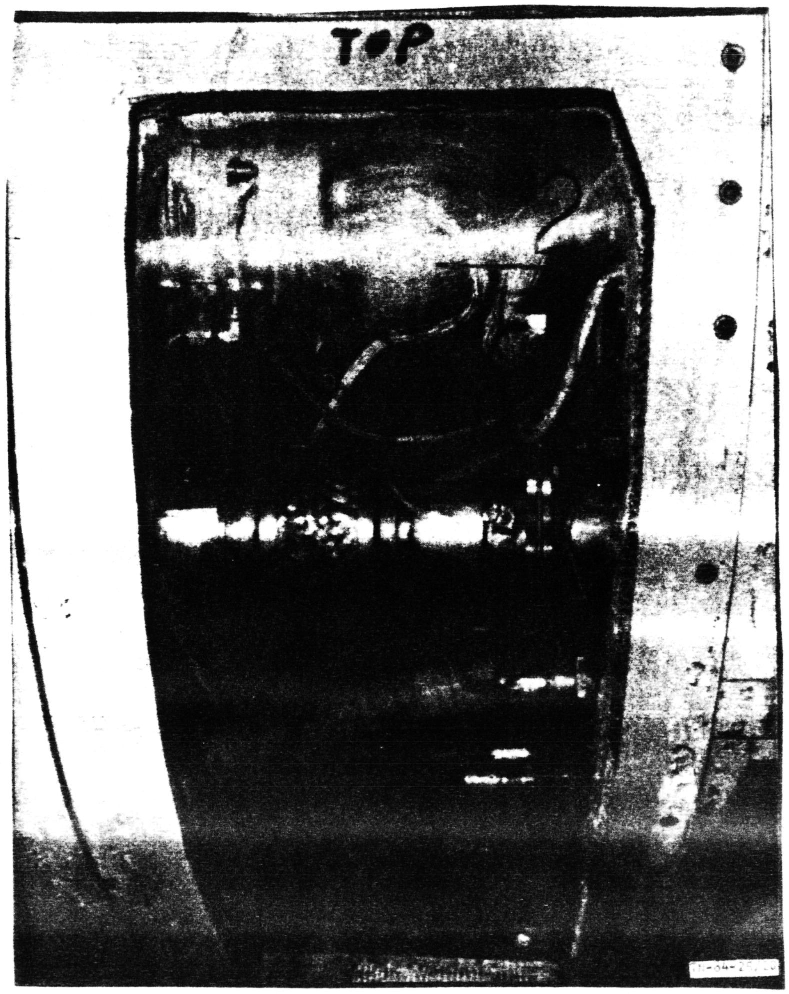


FIGURE 20. TUFT ORIENTATION BETWEEN FS 595/610 (SIDE) WITH FLAPPER DOORS — VENT. 7 LB/SEC.

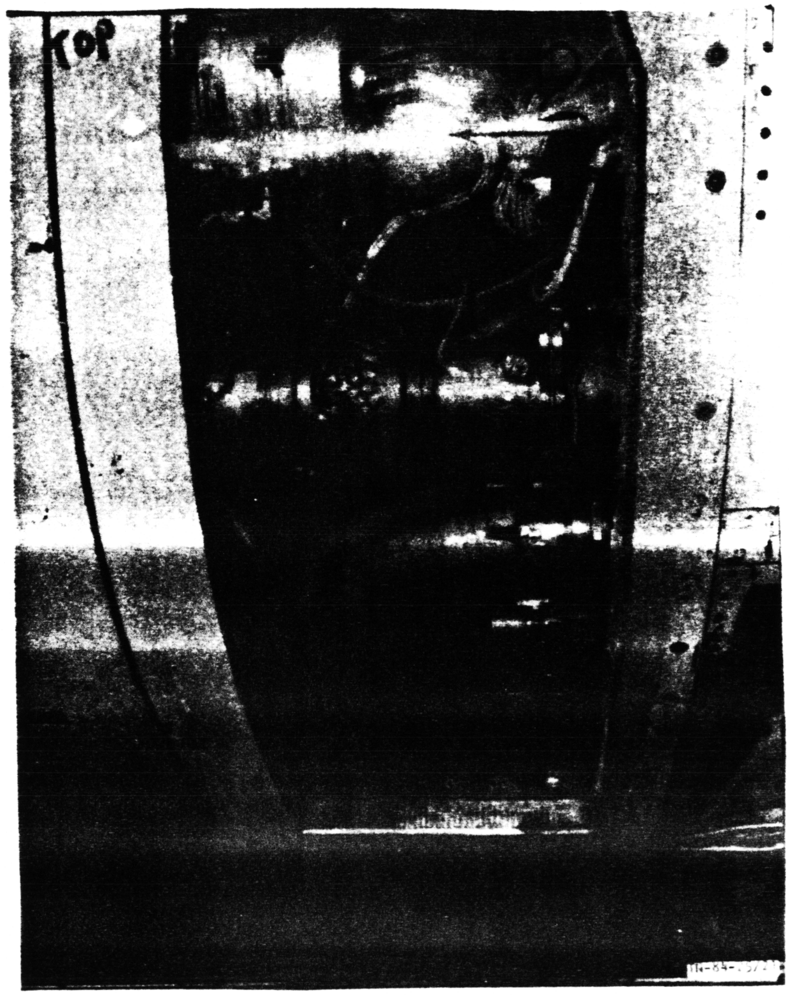


FIGURE 21. TUFT ORIENTATION BETWEEN FS 595/610 (SIDE) WITH FLAPPER DOORS — VENT. RATE 22 LB/SEC.

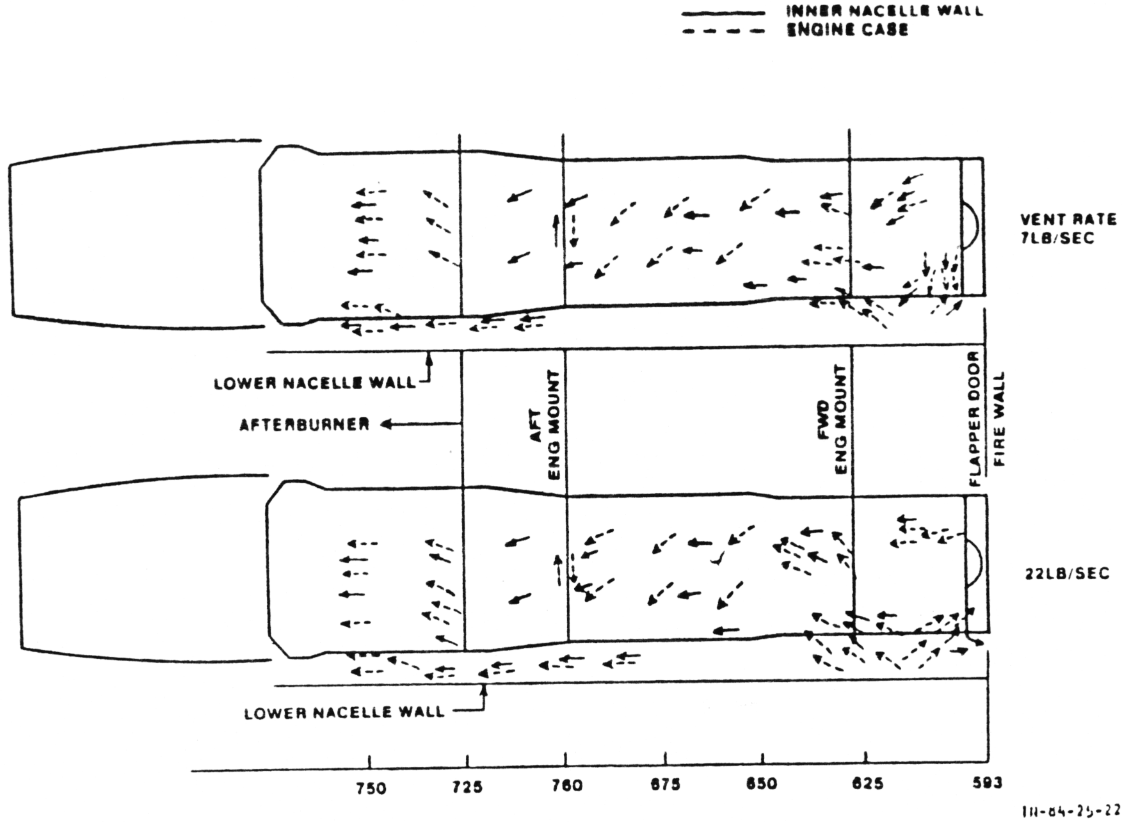


FIGURE 22. SKETCH OF AIRFLOW PATTERNS WITH FLAPPER

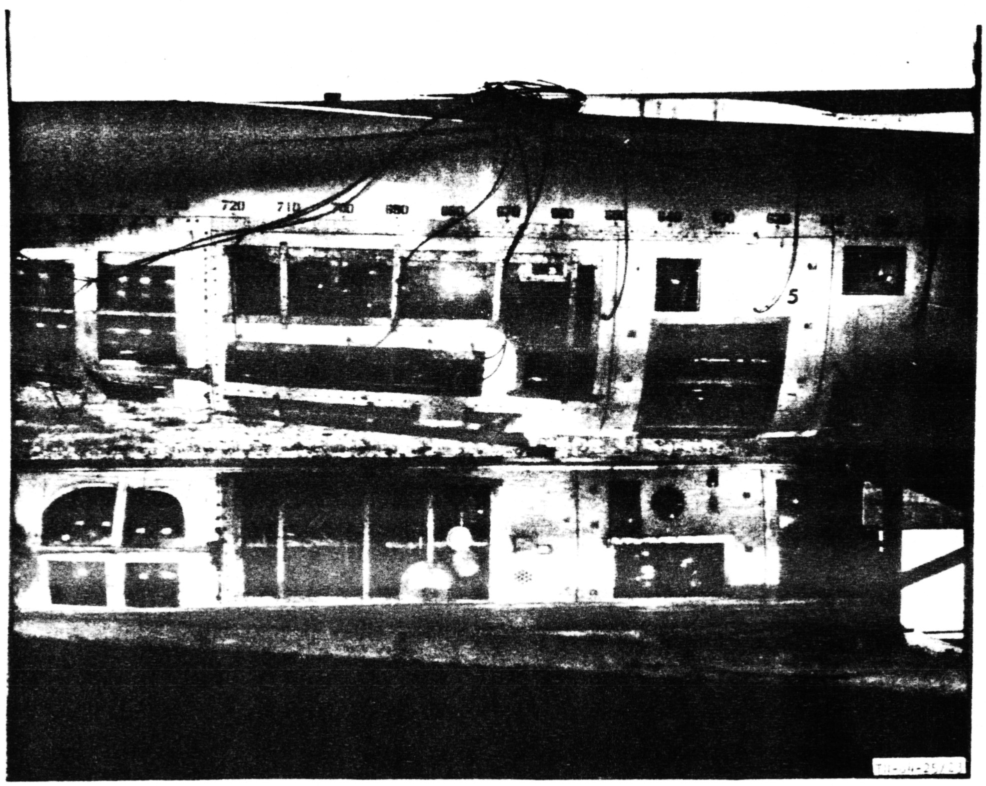


FIGURE 23. F-111 FUSELAGE (WITHOUT FLAPPER DOORS) DURING INTRODUCTION OF CO_2 — VENT. RATE 7 LB/SEC.

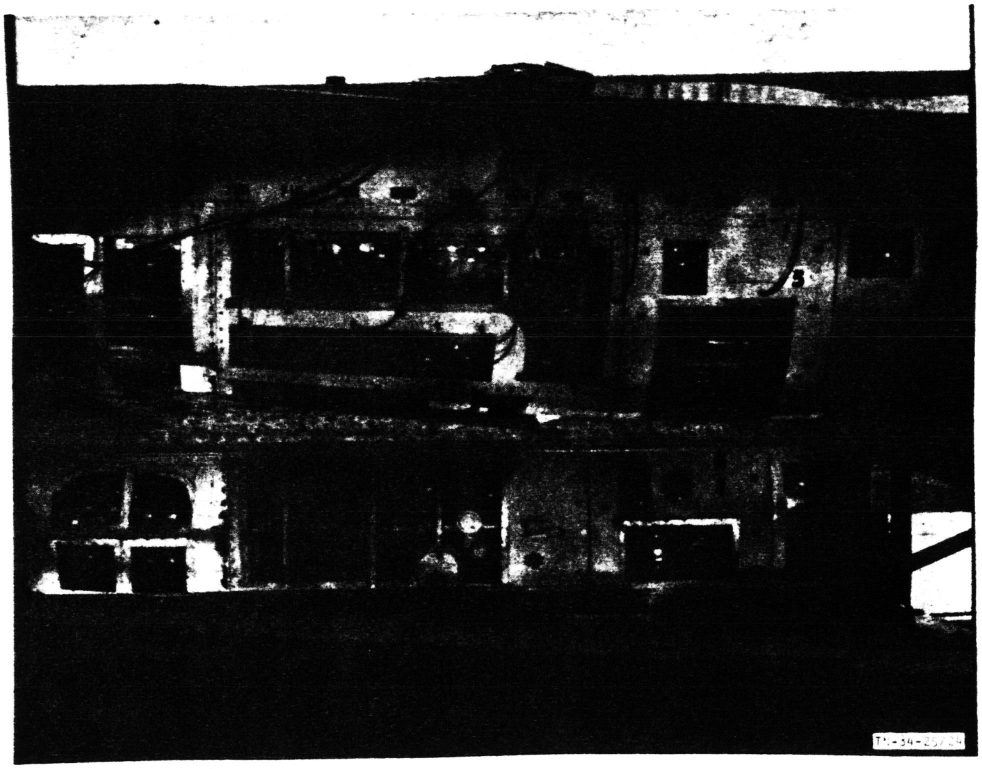


FIGURE 24. OVERALL FUSELAGE VIEW (WITHOUT FLAPPER DOORS) — VENT. RATE 7 LB/SEC.

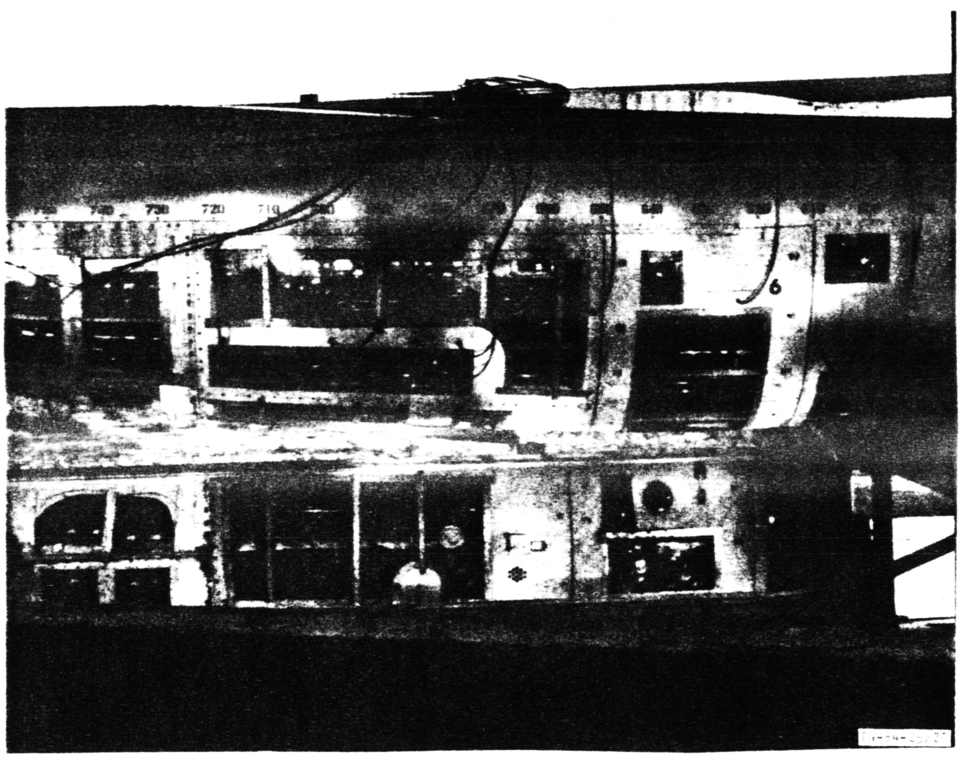


FIGURE 25. OVERALL FUSELAGE VIEW (WITHOUT FLAPER DOORS) — VENT. RATE 22 LB/SEC.

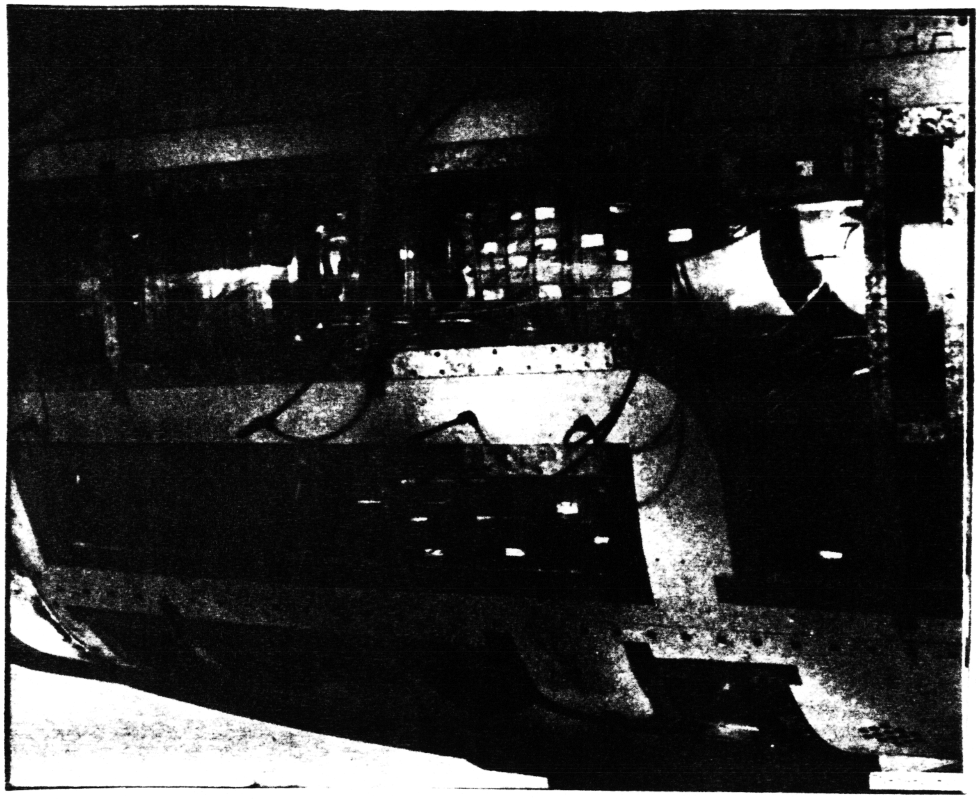


FIGURE 26. TUFT ORIENTATION BETWEEN FS 655/720 (SIDE) WITHOUT FLAPPER DOORS — VENT. RATE 7 LB/SEC.

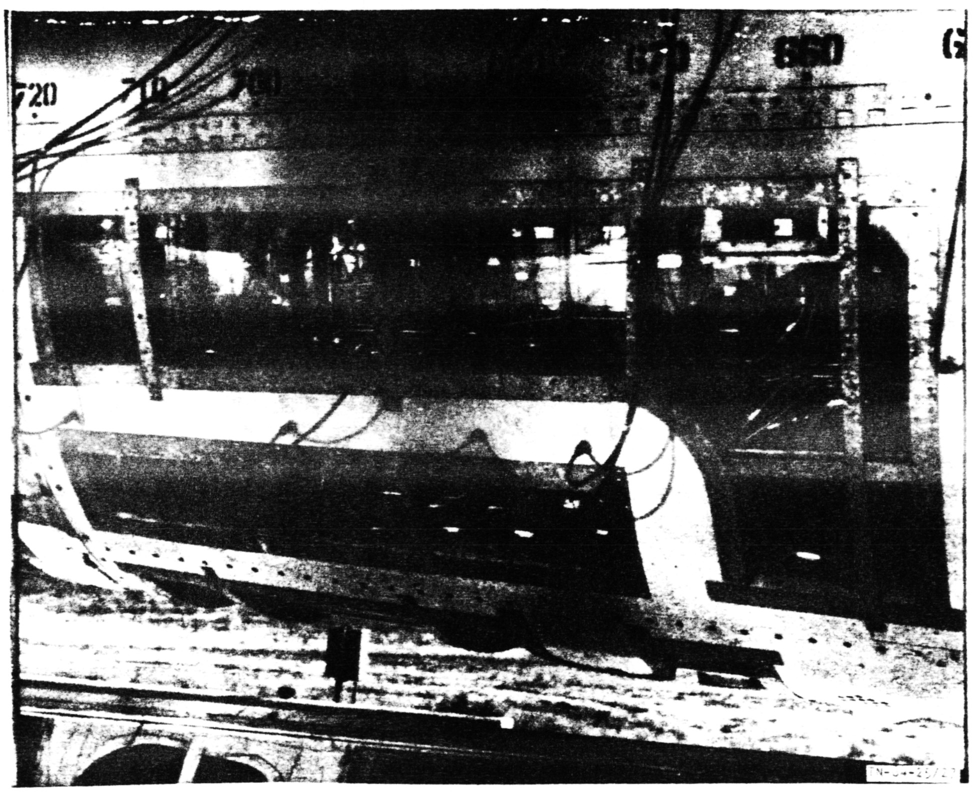


FIGURE 27. TUFT ORIENTATION BETWEEN FS 655/720 (SIDE) WITHOUT FLAPPER DOORS — VENT. RATE 22 LB/SEC.

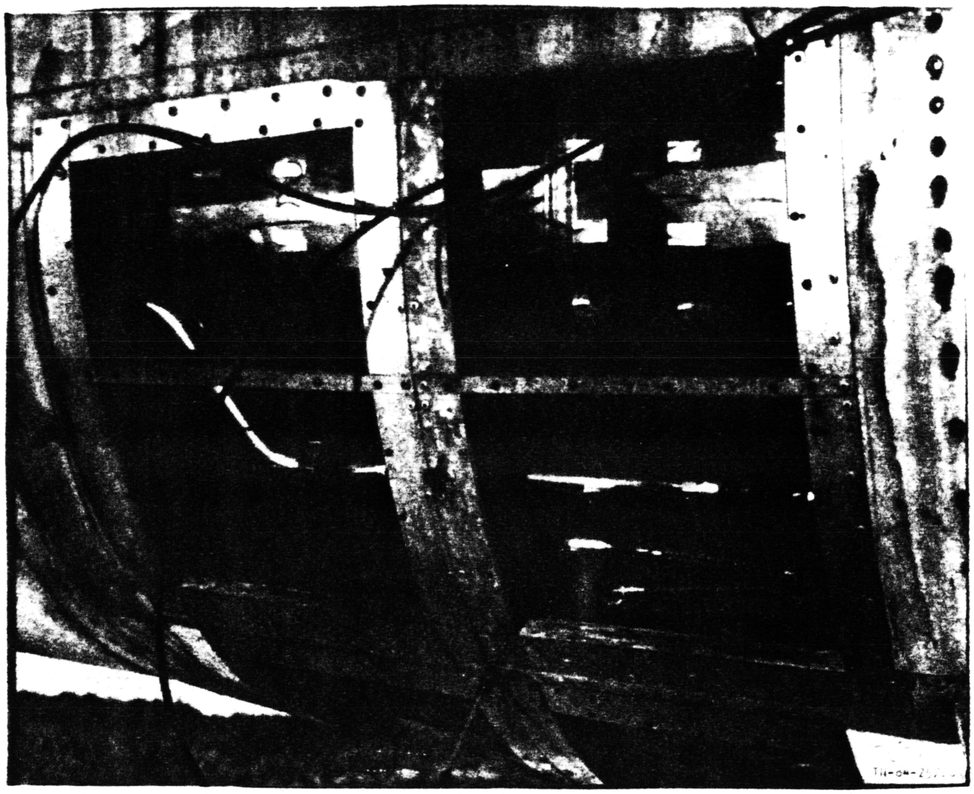


FIGURE 28. TUFT ORIENTATION BETWEEN FS 730/760 (SIDE) WITHOUT FLAPPER DOORS — VENT. RATE 7 LB/SEC.

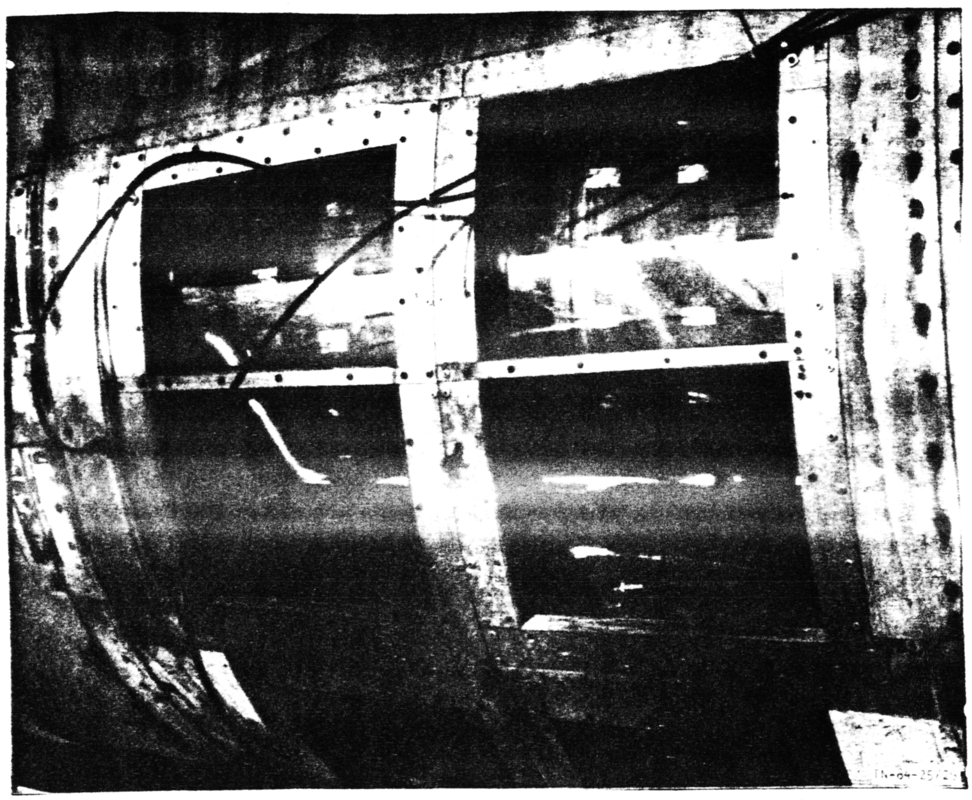


FIGURE 29. TUFT ORIENTATION BETWEEN FS 730/760 (SIDE) WITHOUT FLAPPER DOORS — VENT. RATE 22 LB/SEC.

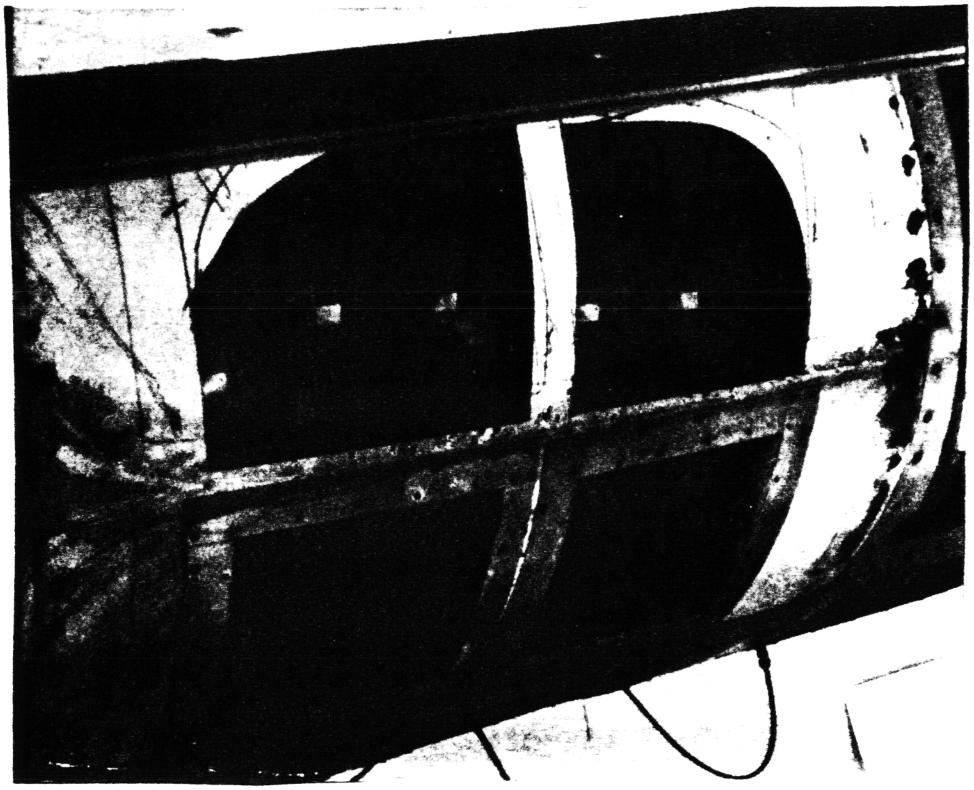


FIGURE 30. TUFT ORIENTATION BETWEEN FS 730/760 (BOTTOM) WITHOUT FLAPPER DOORS — VENT. RATE 7 LB/SEC.

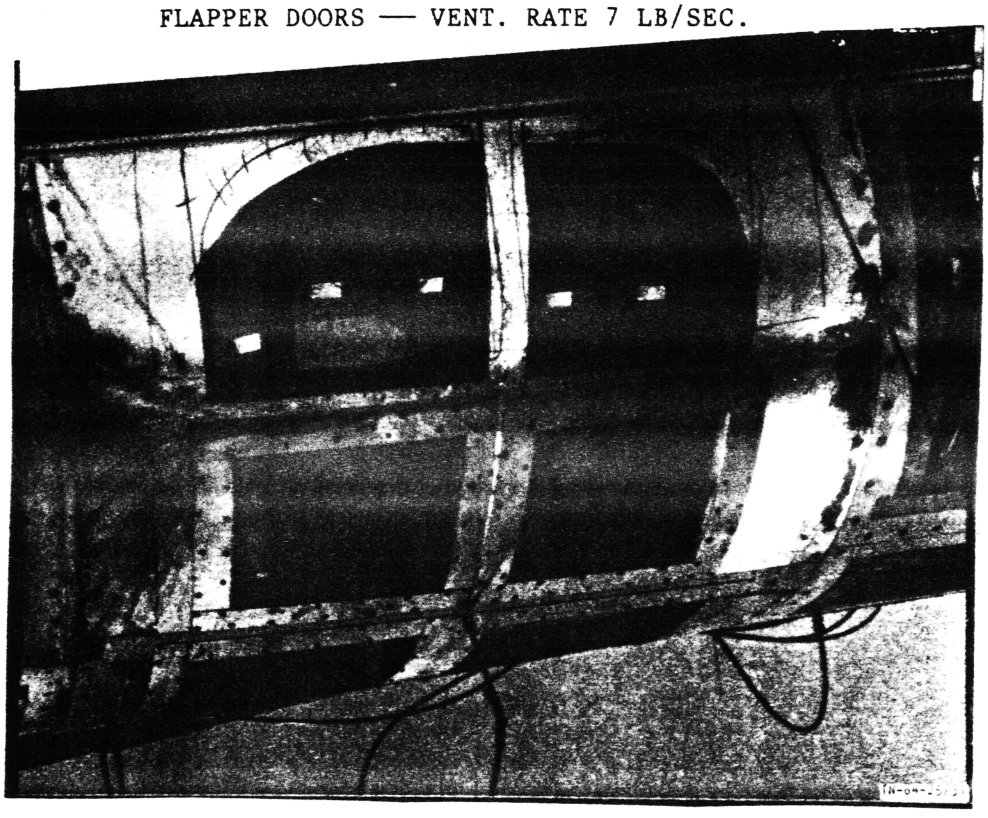


FIGURE 31. TUFT ORIENTATION BETWEEN FS 730/760 (BOTTOM) WITHOUT FLAPPER DOORS — VENT. RATE 22 LB/SEC.

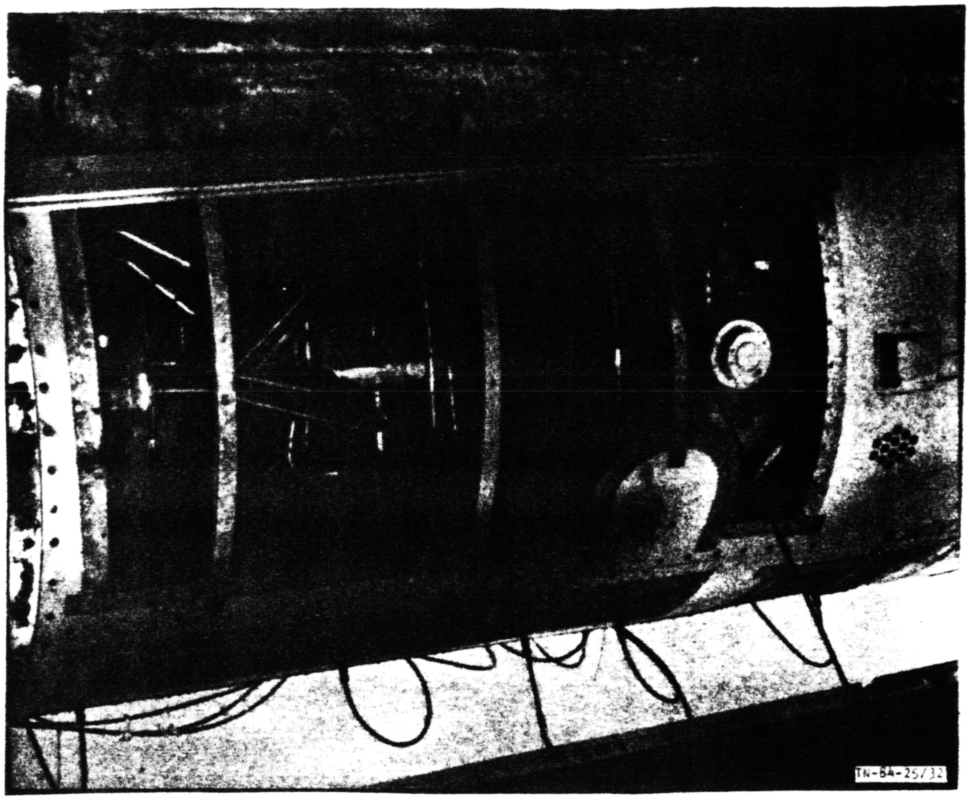


FIGURE 32. TUFT ORIENTATION BETWEEN FS 670/720 (BOTTOM) WITHOUT FLAPPER DOORS — VENT. RATE LB/SEC.

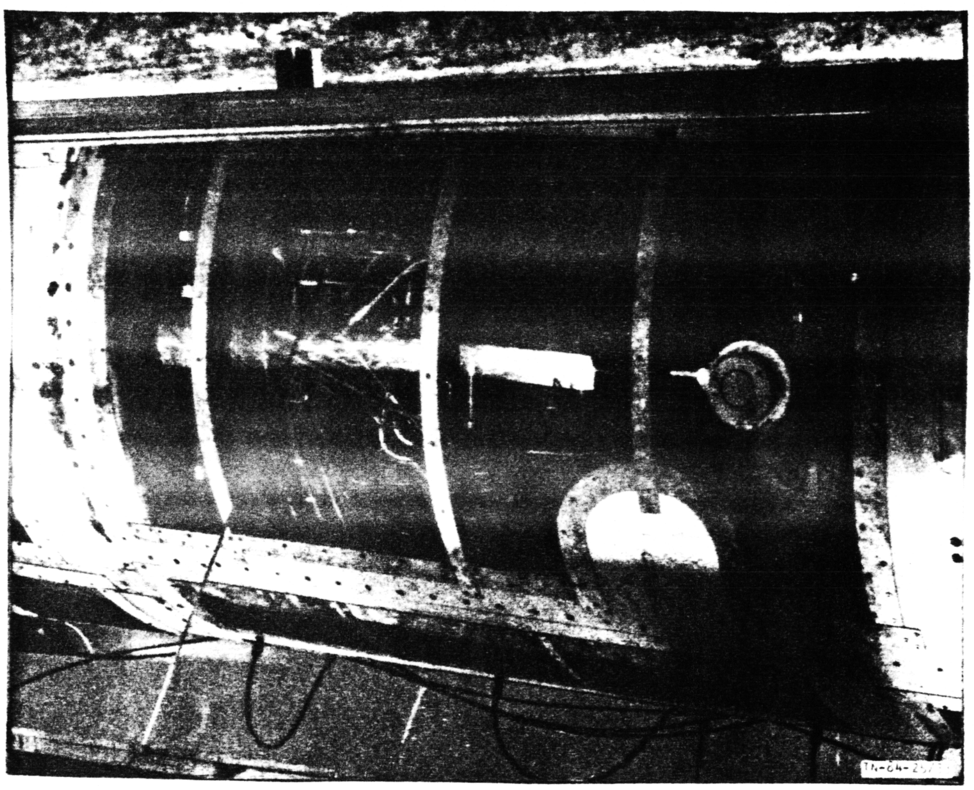


FIGURE 33. TUFT ORIENTATION BETWEEN FS 670/720 (BOTTOM) WITHOUT FLAPPER DOORS — VENT. RATE 22 LB/SEC.

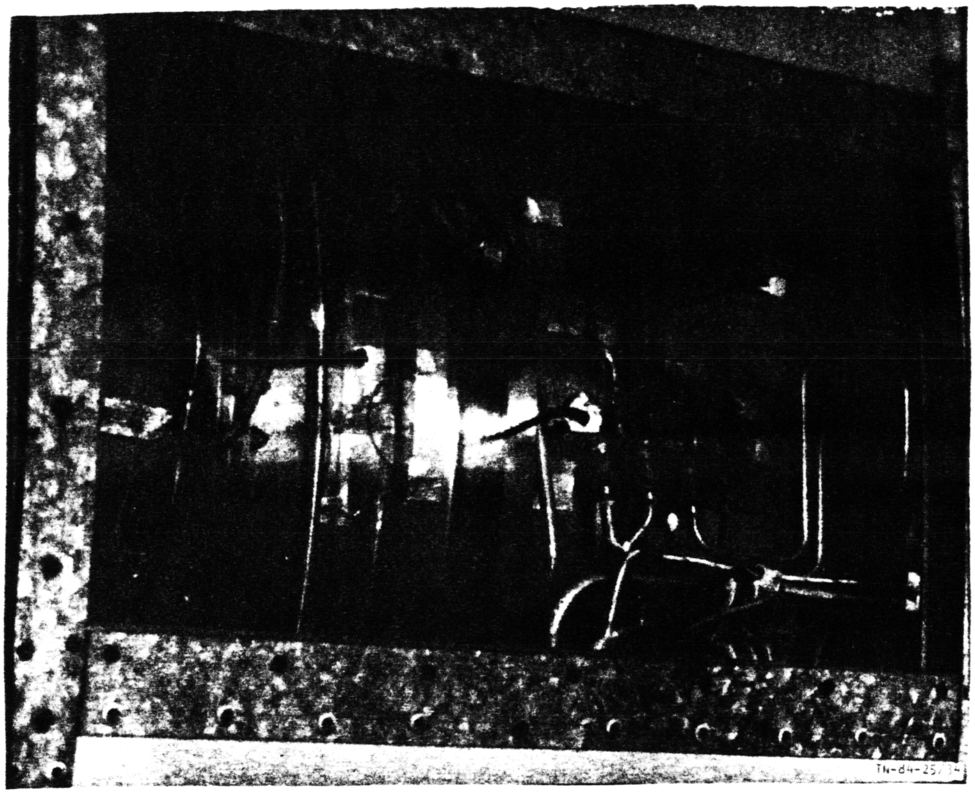


FIGURE 34. TUFT ORIENTATION (WITHOUT FLAPPER DOORS) AROUND OUTBOARD AFT ENGINE MOUNT — VENT. RATE 22 LB/SEC.

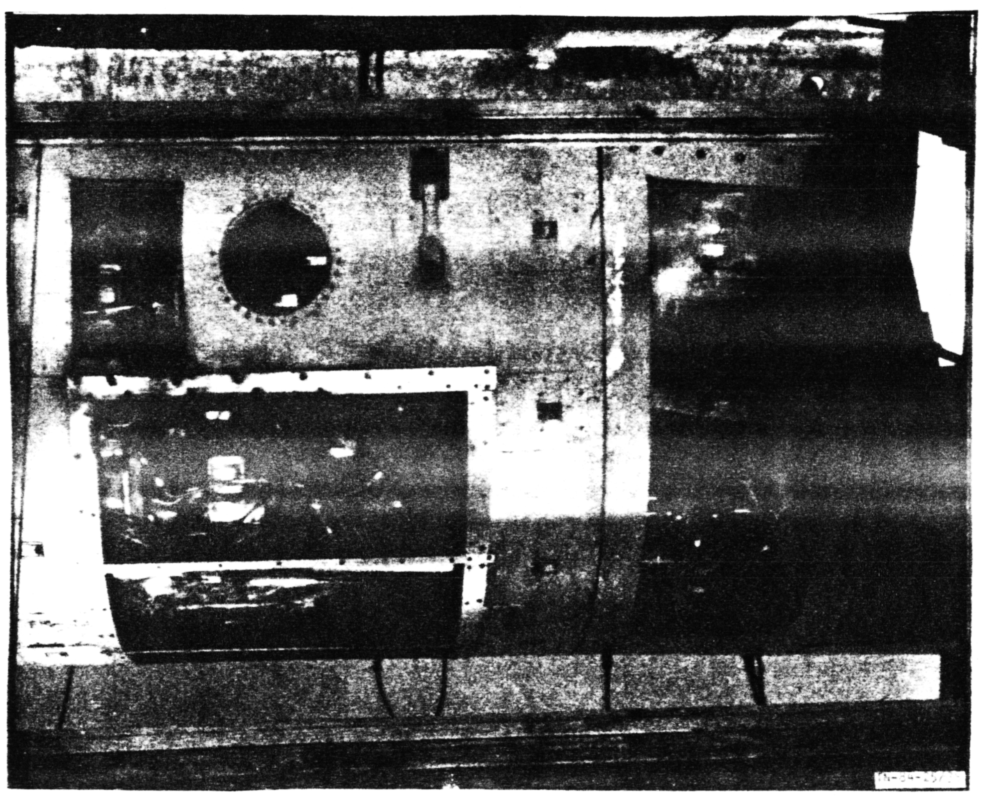


FIGURE 35. TUFT ORIENTATION BETWEEN FS 595/640 (BOTTOM) WITHOUT FLAPPER DOORS — VENT RATE 7 LB/SEC.

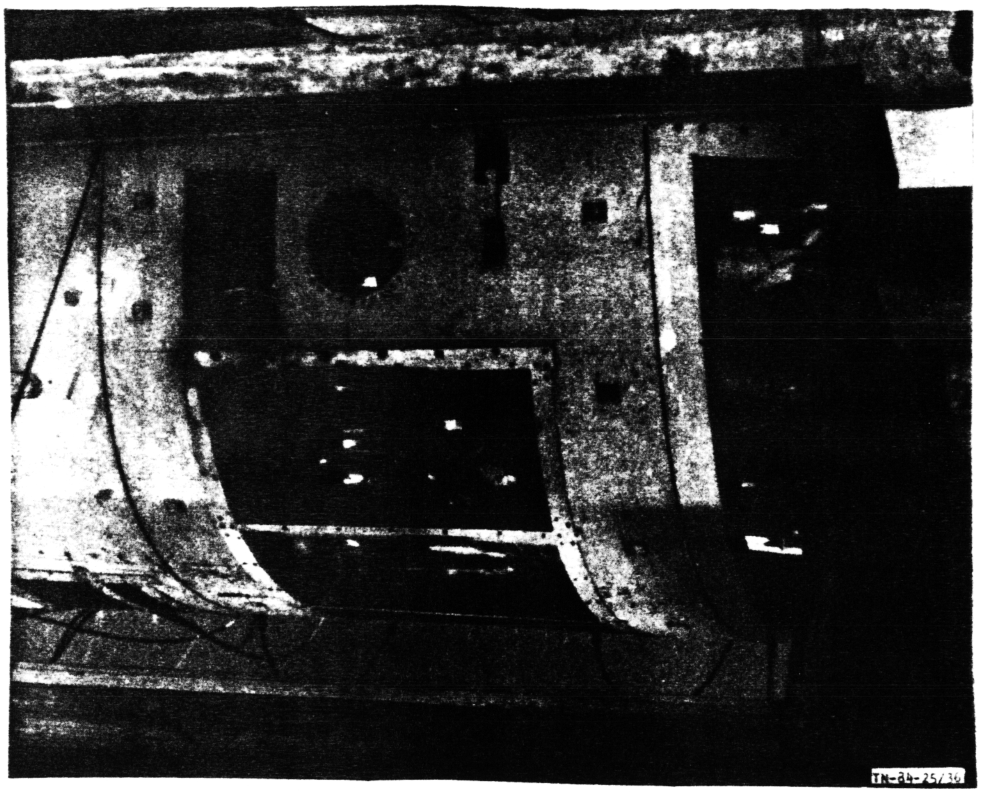


FIGURE 36. TUFT ORIENTATION BETWEEN FS 595/640 (BOTTOM) WITHOUT FLAPPER DOORS — VENT. RATE 22 LB/SEC.

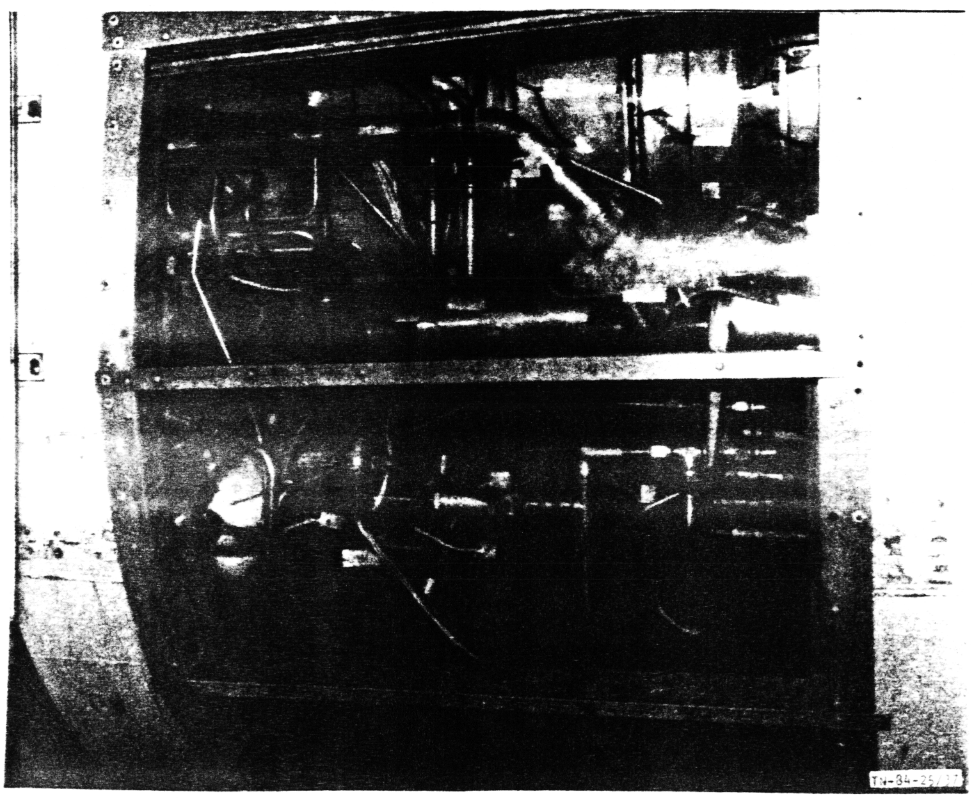


FIGURE 37. TUFT ORIENTATION BETWEEN FS 620/640 (SIDE) WITHOUT FLAPPER DOORS — VENT. RATE 7 LB/SEC.

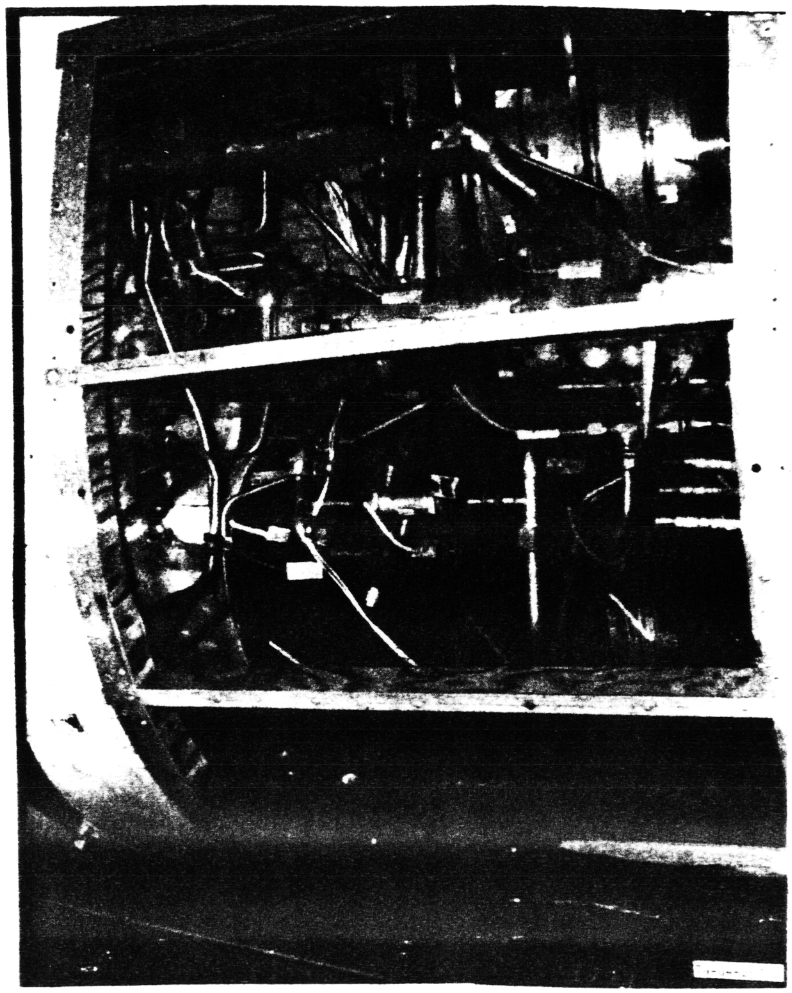


FIGURE 38. TUFT ORIENTATION BETWEEN FS 620/640 (SIDE) WITHOUT FLAPPER DOORS — VENT. RATE 22 LB/SEC.

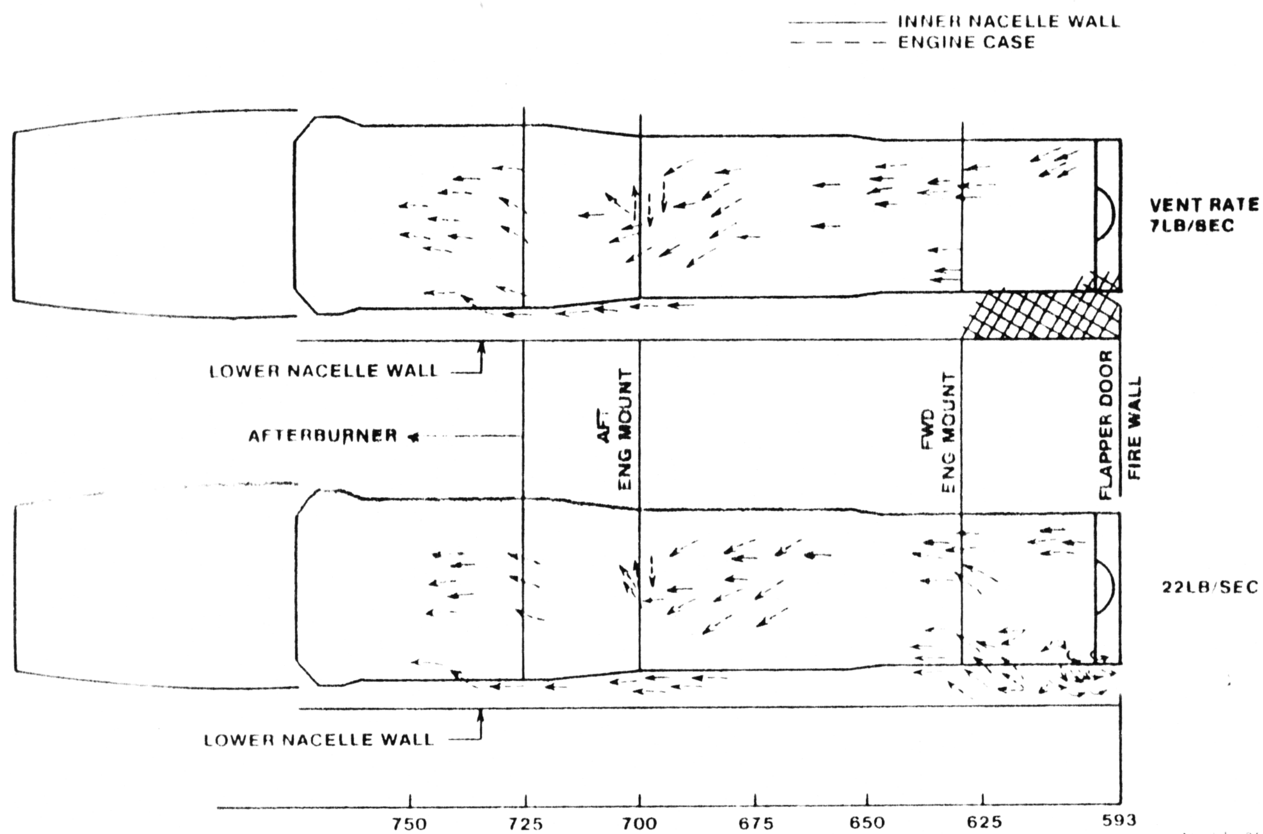


FIGURE 39. SKETCH OF AIRFLOW PATTERNS (WITHOUT FLAPPER DOORS/SIDE VIEW)

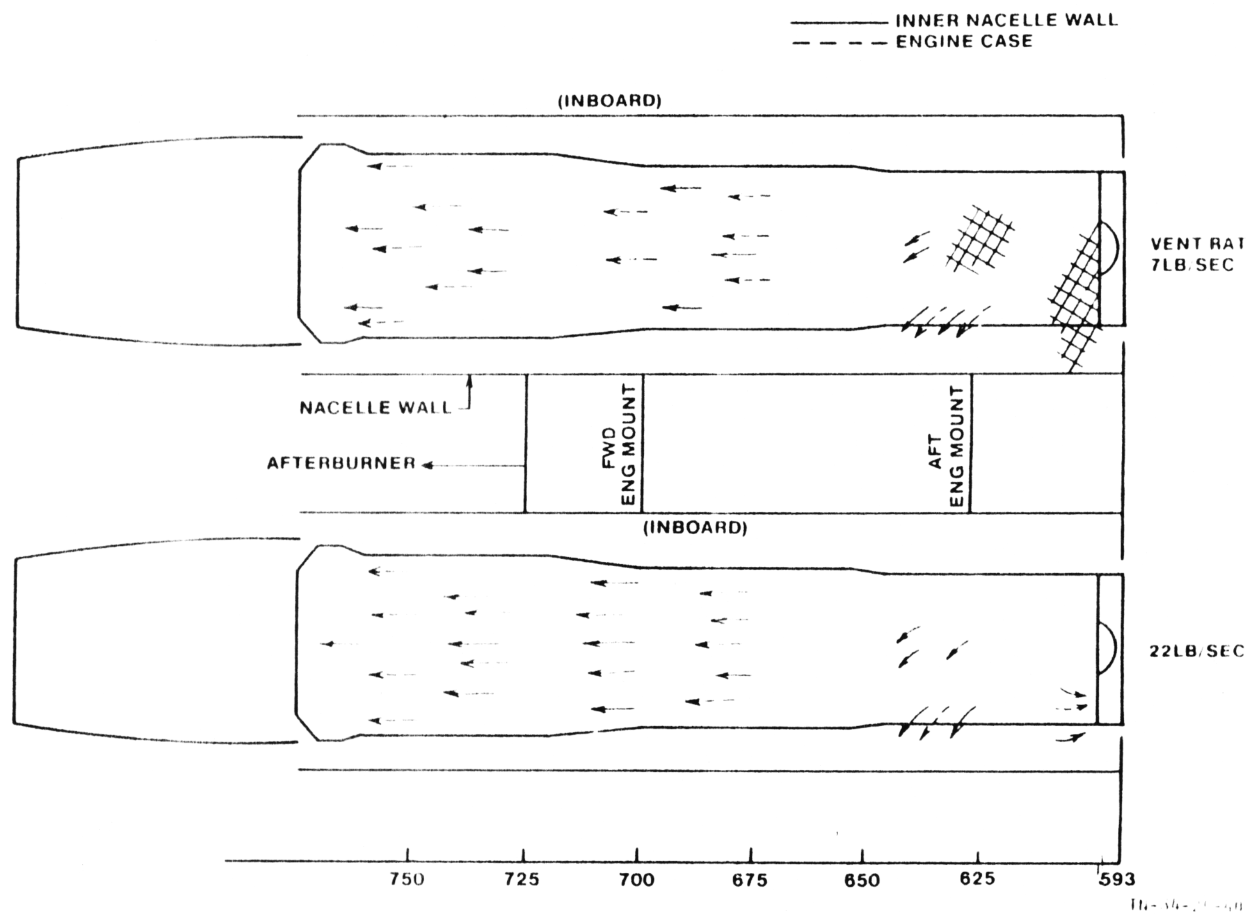


FIGURE 40. SKETCH OF AIRFLOW PATTERNS (WITHOUT FLAPPER DOORS/BOTTOM VIEW)

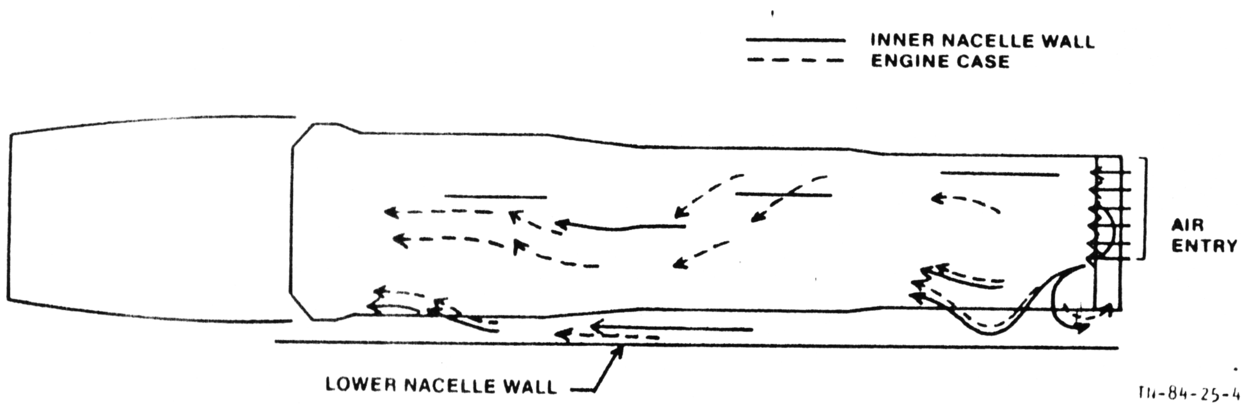


FIGURE 41. APPROXIMATION OF OVERALL AIRFLOW PATTERN