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Water-Tunnel Study Results of a TF/A-18 and F/A-18 Canopy Flow Visualization

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ABSTRACT

A water-tunnel study examining the influence of canopy shape on canopy and leading-edge extension flow patterns was initiated at the NASA Ames Research Center, Dryden Flight Research Facility, Flow Visualization Facility. The F/A-18 single-place canopy model and the TF/A-18 two-place canopy model were the study subjects. Plan view and side view photographs showing the flow patterns created by injected colored dye are presented for 0° and 5° sideslip angles. Photographs taken at angle-of-attack and sideslip conditions correspond to test departure points found in flight test. Flight experience has shown that the TF/A-18 airplane departs in regions where the F/A-18 airplane is departure-resistant. The study results provide insight into the differences in flow patterns which may influence the resulting aerodynamics of the TF/A-18 and F/A-18 aircraft. It was found that at 0° sideslip, the TF/A-18 model has more downward flow on the sides of the canopy than the F/A-18 model. This could be indicative of flow from the leading-edge extension (LEX) vortexes impinging on the sides of the wider TF/A-18 canopy. In addition, the TF/A-18 model has larger areas of asymmetric separated and unsteady flow on the LEXs and fuselage, possibly indicating a lateral and directional destabilizing effect at the conditions studied.

NOMENCLATURE

FS	fuselage station
KCAS	calibrated airspeed, kn
L	fuselage length
LEX	leading-edge extension
V_∞	free-stream velocity, ft/sec
x	fuselage reference station
α	angle of attack, deg
β	angle of sideslip, deg

INTRODUCTION

Initial flight testing of the F/A-18 full-scale development aircraft involved extensive analysis of the single-seat high-angle-of-attack flying qualities and spin characteristics. Although there was some spot checking of the spin characteristics of the two-seat TF/A-18 airplane, little attention was given to the differences between the two airplanes. Flight experience has shown that the TF/A-18 airplane exhibited markedly different characteristics when departures from controlled flight occurred in regions where the single-place airplane was departure-resistant: below Mach 0.7 at 30° to 35° angle of attack, and below 10° angle of attack at low speed—below 250 kn calibrated airspeed (KCAS) (ref. 1).

Since the external differences between the F/A-18 and TF/A-18 aircraft are the size and shape of the canopies, the difference in flying qualities between the two aircraft at high angles of attack could stem from differences in flow characteristics about the canopy, or canopy flow creating an unfavorable effect on the leading-edge extension (LEX) vortexes. A water-tunnel flow visualization test was performed at the NASA Ames Research Center, Dryden Flight Research Facility to evaluate these flow interactions. Previous water-tunnel tests have been useful in the past to examine the vortical flow about the single-place F/A-18 aircraft. One test investigated the F/A-18 LEX vortex and vertical tail interaction at high angle of attack (ref. 2). A second water-tunnel test closely analyzed the separated flow from the forebody, wing, and LEX. This was an attempt to explain the reasons for the discrepancy in lateral stability at high angle of attack observed from the results of tests conducted with different-sized wind tunnels and two different-sized models (ref. 3). The primary purpose of the test described in this study was to visualize and document flow fields about the F/A-18 and TF/A-18 model canopies at high angle of attack, and note any separation or interaction with the LEX vortexes.

This study emphasized the flow fields about the canopies of each configuration. It did not provide information on the high-angle-of-attack forebody flow field. The study was limited to the angle-of-attack and sideslip conditions examined. This paper includes photographs and sketches taken only at angle-of-attack and sideslip conditions corresponding to departure conditions discovered in actual flight.

Experimental Methods

Water-Tunnel Facility

The NASA Ames-Dryden Flow Visualization Facility is a single-return water tunnel used for visualization of complex three-dimensional flow fields. The water tunnel is presented schematically in figure 1. The test section is 24 by 16 by 72 in. and has walls made of 2-in. thick transparent acrylic plastic panels. The water-tunnel velocity range can be varied from 0.6 in/sec to 13.2 in/sec, however, this experiment was conducted at 3.0 in/sec. At this flow rate, the velocity profile remains within 1 percent of the centerline velocity over the majority of the test section, with a turbulence level between 2 and 3 percent (ref. 4).

Model Description

The water-tunnel flow visualization studies were conducted with 1/48-scale models of the F/A-18 and TF/A-18 aircraft. The external differences in the two models (and in the actual aircraft) are the size and shape of the canopies. In the actual aircraft the two-place canopy is 54 in. longer, 8.4 in. higher, and 4 in. wider than the single-place canopy. The F/A-18 and TF/A-18 canopy moldline comparison is shown in figure 2. The model configuration was tested with landing gear up and a leading-edge wing flap deflection of 34° leading edge down. This is the scheduled leading-edge flap deflection when the actual aircraft is flying at 26° or greater angle of attack.

To visualize the flow field, the models were equipped with dye tubes. The dye tubes were mounted internally and externally and led to dye ports installed on the leading edge of the LEXs, the side of the fuselage, and on the canopy. Each LEX featured three dye release ports located on the underside of each leading edge. The single-place canopy featured two lateral rows of three dye release ports. The longer two-place canopy featured three lateral rows of three dye release ports. Each fuselage side featured two dye release ports below the canopy.

Test Procedures

The water-tunnel flow visualization is obtained by the injection of colored food dyes having the same density as water into the flow field. The dye is injected by pressurizing the dye supply and controlling the flow to the model dye tubes by means of needle valves.

The water tunnel was operated at a test section velocity of 3.0 in/sec, which has been found to produce the best flow visualization results. This velocity corresponds to a Reynolds number of 2.3×10^4/ft.

Inlet flows were simulated in the water tunnel by applying suction to tubes connected to the models' exhaust nozzles. The tubes were connected to a water flowmeter outside the tunnel. The flowmeter was used to measure and accurately set the inlet flow rate.

The test program was videotaped and photographed using 120-mm color film. The video camera and 120-mm still camera were first set up for the planform view where photographs were taken at various angles of attack with sideslip held constant. The cameras were then repositioned and the angle-of-attack positions repeated to view the corresponding leeward (left) side view. Consequently, the planform and side views were not taken simultaneously.

Results and Discussion

The F/A-18 and TF/A-18 high-angle-of-attack flow field is dominated by separation-induced vortex flow from the fuselage forebody and LEXs. Strong vortexes develop from the sharp-edged LEXs, while weaker vortexes roll up from the forebody. This flow phenomenon is illustrated in a Northrop water-tunnel photograph in figure 3 (ref. 3).

In this experiment it was discovered that the entrainment of colored dye into the forebody vortexes resulted in obscuring the view of the canopy flow field. For this reason the fuselage forebody flow field was not visualized. The effects of forebody flow field on the canopy flow field are not addressed in this study.

In this study, the emphasis was placed on visualizing the flow about the canopy since it is the only physical difference between the F/A-18 and TF/A-18 configurations. The study was also limited to examining those points at high angle of attack where departures occurred with the TF/A-18 aircraft and not with the F/A-18 aircraft. Data at angles of attack of 30°, 35°, and 40° were taken with and without sideslip.

Canopy Flow Field With 0° Sideslip

Figure 4 shows a side view of the LEX vortex and the flow about the canopy at 30° angle of attack for the F/A-18 model (fig. 4(a)) and TF/A-18 model (fig. 4(b)). The LEX vortex location and breakdown points are nearly identical. The flow about the canopy of the TF/A-18 model shows much more downward flow beginning at the canopy front. This could be indicative of flow from the LEX vortexes impinging on the sides of the wider TF/A-18 canopy.

In the plan view (fig. 5) at 30° angle of attack, the flow over the canopy and the left- and right-LEX vortex breakdown points are nearly symmetrical on the F/A-18 model (fig. 5(a)). On the TF/A-18 model (fig. 5(b)), the left- and right-LEX vortex breakdown points are nearly symmetrical also. The TF/A-18 model, however, shows a large region of reversed flow on the left LEX between $x/L = 0.4$ and 0.5 that is not evident on the F/A-18 model. This region of flow occurs on the model surface, below the primary LEX vortex. The areas of reversed separated flow can be seen more clearly in figures 6 and 7. These figures were drawn using the previous photos, with the aid of reviewing videotape recordings of the flows. The TF/A-18 model shows much larger areas of asymmetric separated and unsteady flow on the LEX and fuselage. This separated and unsteady flow on the LEX and fuselage could cause asymmetrical lift on the LEX and asymmetrical side forces on the fuselage. Since these areas are forward of the aircraft center of gravity they could have a lateral and directional destabilizing effect.

As seen in the side views of figure 8, at 35° angle of attack, again the LEX vortex location and breakdown point are nearly identical. The flow about the F/A-18 canopy (fig. 8(a)) shows a shift from the streamwise flow at 30° angle of attack to a slight downward dispersed flow beginning at the center of the canopy. The flow then resumes its streamwise flow and turns down past the rear of the canopy. The flow about the canopy of the TF/A-18 model (fig. 8(b)) shows a more pronounced downward flow pattern than the previous 30° angle of attack flow pattern. These flow patterns indicate an even stronger impinging effect of the LEX vortex on the canopies at 35° angle of attack than the 30° angle-of-attack condition.

In the plan view (fig. 9) at 35° angle of attack, the flow over the canopies and the left- and right-LEX breakdown points are nearly symmetrical. Once again the TF/A-18 model (fig. 9(b)) shows regions of reverse flow on the left and right LEX between $x/L = 0.35$ and $x/L = 0.45$ and below the primary LEX vortex. This phenomenon is not evident on the F/A-18 model (fig. 9(a)) and is illustrated in figures 10 and 11. Since these areas of separated and unsteady flow are forward of the aircraft center of gravity, it could indicate a lateral and directional destabilizing effect.

Figure 12 shows a side view of the LEX vortexes and flow about the canopy at 40° angle of attack for the F/A-18 model (fig. 12(a)) and TF/A-18 model (fig. 12(b)). The dye pattern about the F/A-18 canopy flows back streamwise and turns down just before the rear of the canopy. The flow about the TF/A-18 model still shows downward flow beginning at the front of the canopy. A point of interest is the location of the LEX breakdown points in relation to the canopies. Although the LEX vortex locations and breakdown points have nearly identical x/L locations relative to the model fuselage, they have different effects on the canopy flows. Because of the longer canopy of the TF/A-18 model, the vortex breakdown causes the canopy flow to become very unsteady at and aft of the breakdown point. With the F/A-18 model and its smaller canopy, the vortex breakdown occurs aft of the canopy and does not affect the steadiness of the canopy flow.

In the plan view (fig. 13) at 40° angle of attack, the flow over the canopies and the left- and right-LEX breakdown points are nearly symmetrical. At this angle of attack the LEX flow appears entirely unsteady, with little or no reverse flow on both the TF/A-18 and F/A-18 LEXs (figs. 14 and 15).

Canopy Flow Field With 5° Sideslip

When the TF/A-18 and F/A-18 configurations were subjected to a 5° sideslip, the flow fields showed all of the 0° sideslip characteristics except two. As seen in the leeward side view, (fig. 16) at 35° angle of attack, both the F/A-18 (fig. 16(a)) and TF/A-18 (fig. 16(b)) canopies exhibit a downward dye flow beginning at the front of the canopies. Specifically, this is a change in flow for the F/A-18 canopy from 0° sideslip. Sideslipping the F/A-18 canopy configuration results in a shift from the nearly streamwise flow seen at 0° sideslip (fig. 8(a)) to a downward flow shown in figure 16(a). It appears that the LEX vortex has a more dominant effect on the flow about the leeward side of the canopy with sideslip on the F/A-18 model, than it did with 0° sideslip.

The second key flow feature generated on the F/A-18 and TF/A-18 model, as a result of a sideslip, was the formation of a weak vortex off the front and windward side of the canopies (figs. 16 and 17). As the photos show, even though the canopies are of different dimensions, the vortexes appear in the same location. The difference, as seen in figure 16, is the size of the diameter of the vortex cores. The TF/A-18 model with its larger canopy, creates a larger vortex core diameter than the one generated from the F/A-18 canopy.

CONCLUDING REMARKS

A preliminary investigation of the flow about the canopies of the F/A-18 and TF/A-18 models was conducted in the NASA Ames Research Center, Dryden Flight Research Facility water tunnel. These tests were conducted because departures were experienced in flight with the TF/A-18 aircraft that were not experienced by the F/A-18 aircraft.

No change was noted in the position of the leading-edge extension (LEX) vortexes or breakdown points between the models. However, at 30° to 40° angle of attack the TF/A-18 model had significantly more downward flow on the sides of the canopy and less streamwise flow than the F/A-18 model. In addition, the TF/A-18 model had a much larger region of asymmetric separated and unsteady flow on the LEX and side of the fuselage near the canopy that did not appear on the F/A-18 model. This could indicate a lateral and directional destabilizing effect since the asymmetric flow is forward of the aircraft center of gravity.

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Dryden Flight Research Facility
National Aeronautics and Space Administration
Edwards, California, June 22, 1989

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4. Hall, Capt. Robert M., and John H. Del Frate, *Interaction Between Forebody and Wing Vortices—A Water Tunnel Study*, AFWAL-TM-85-252, Jan. 1986.

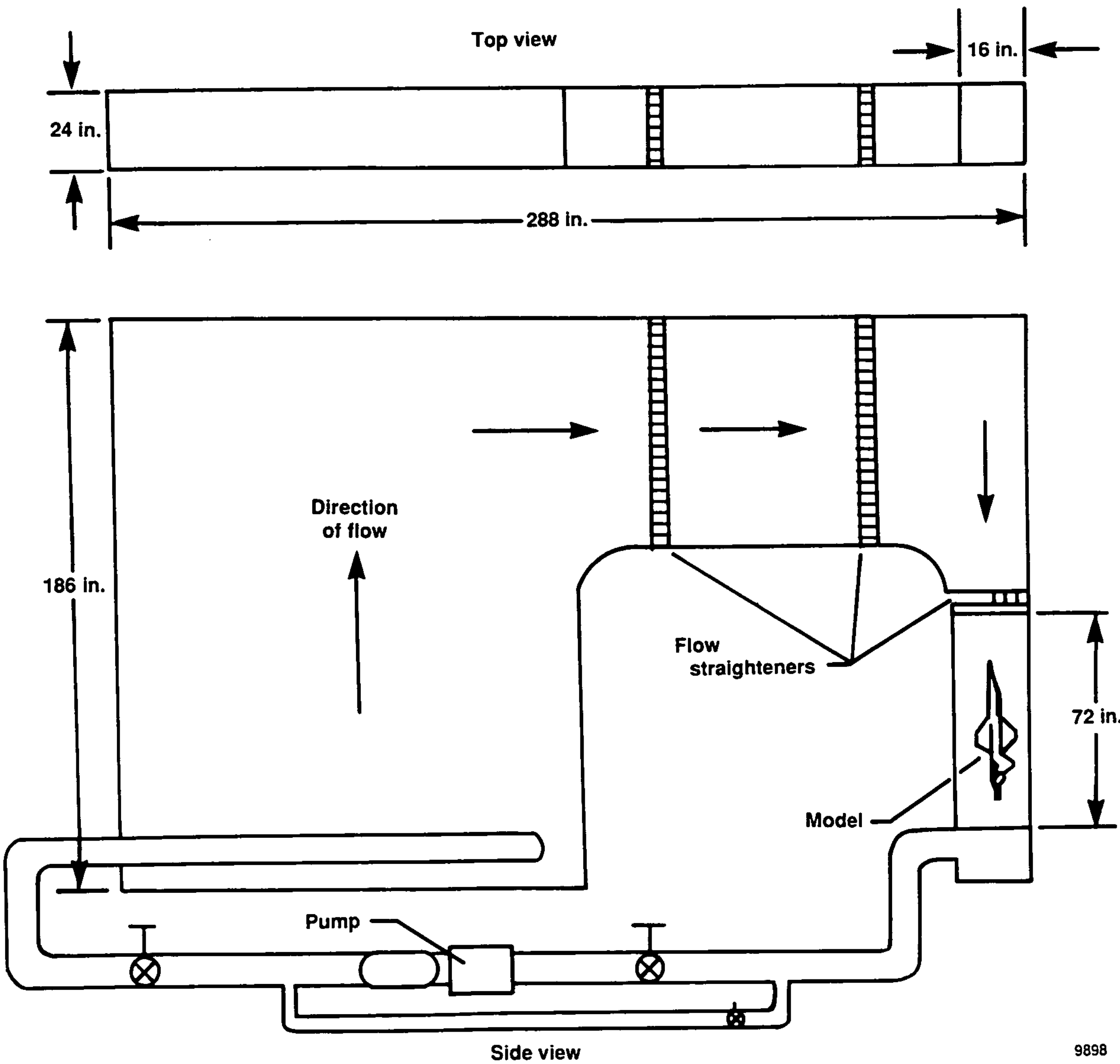
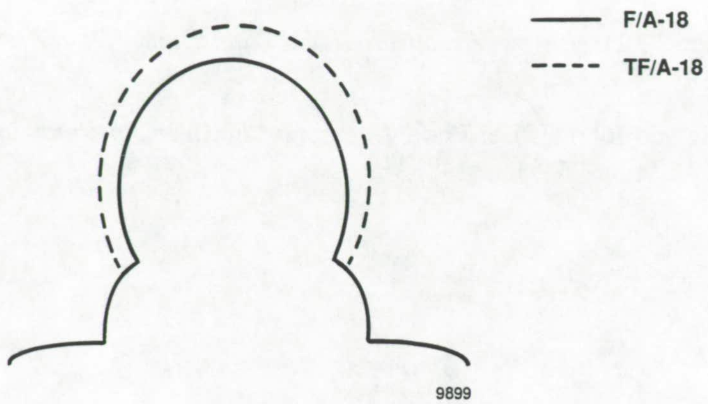
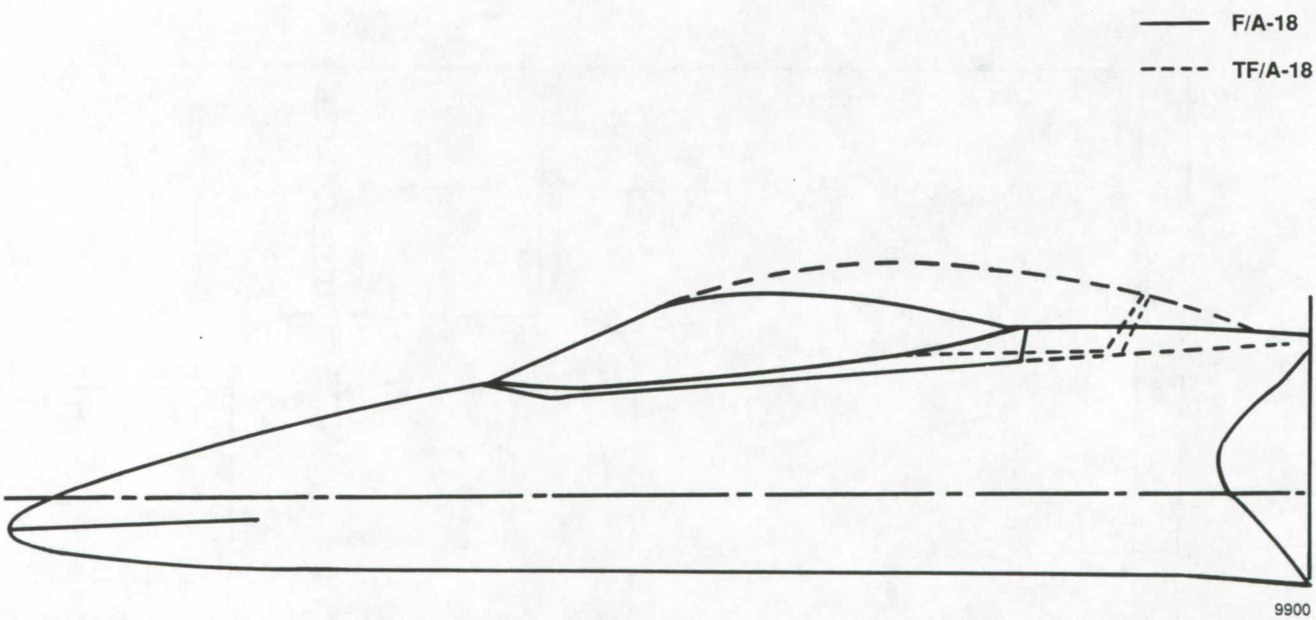


Figure 1. Schematic of Ames-Dryden water tunnel.



(a) Front view of canopy.



(b) Side view of canopy.

Figure 2. Canopy moldline comparison.

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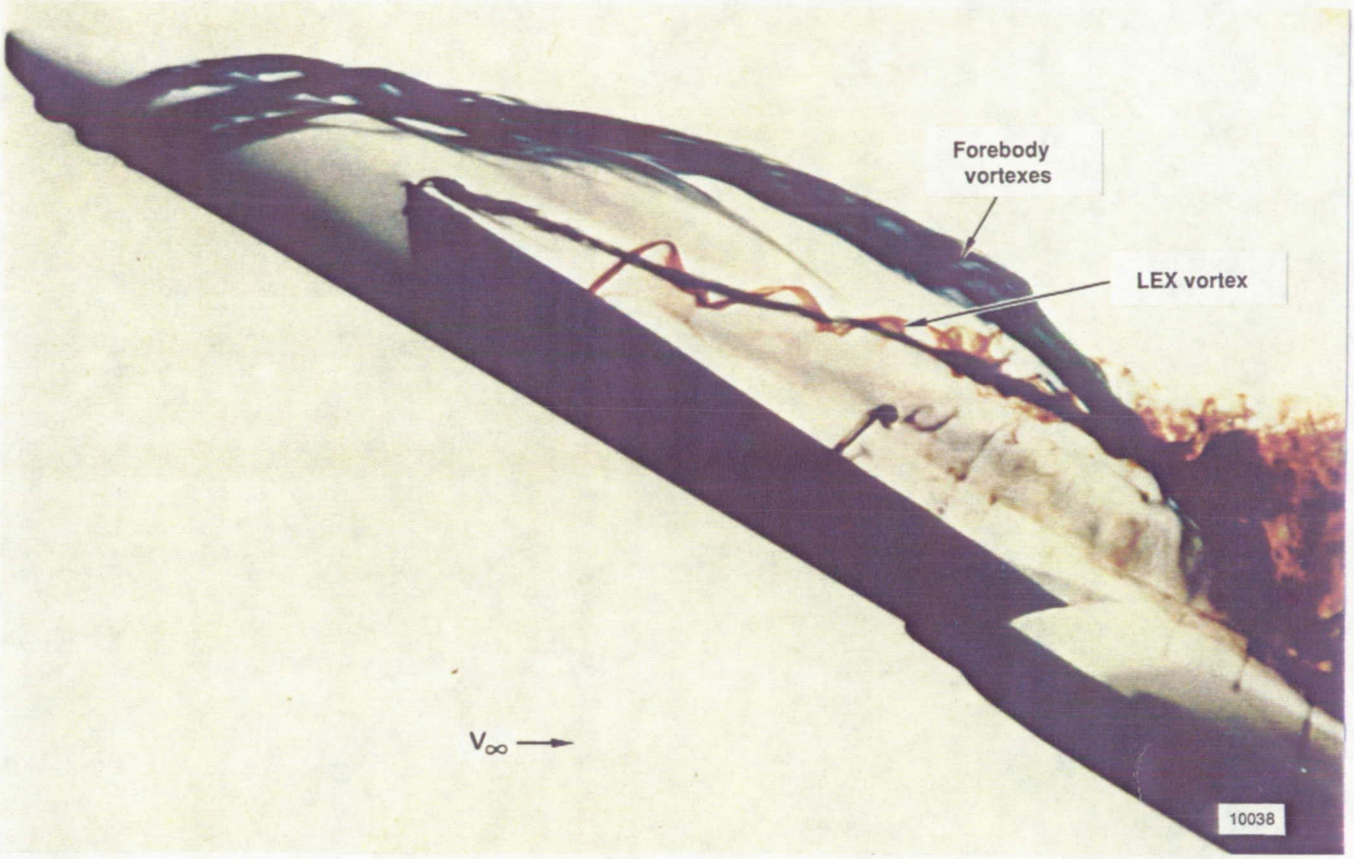
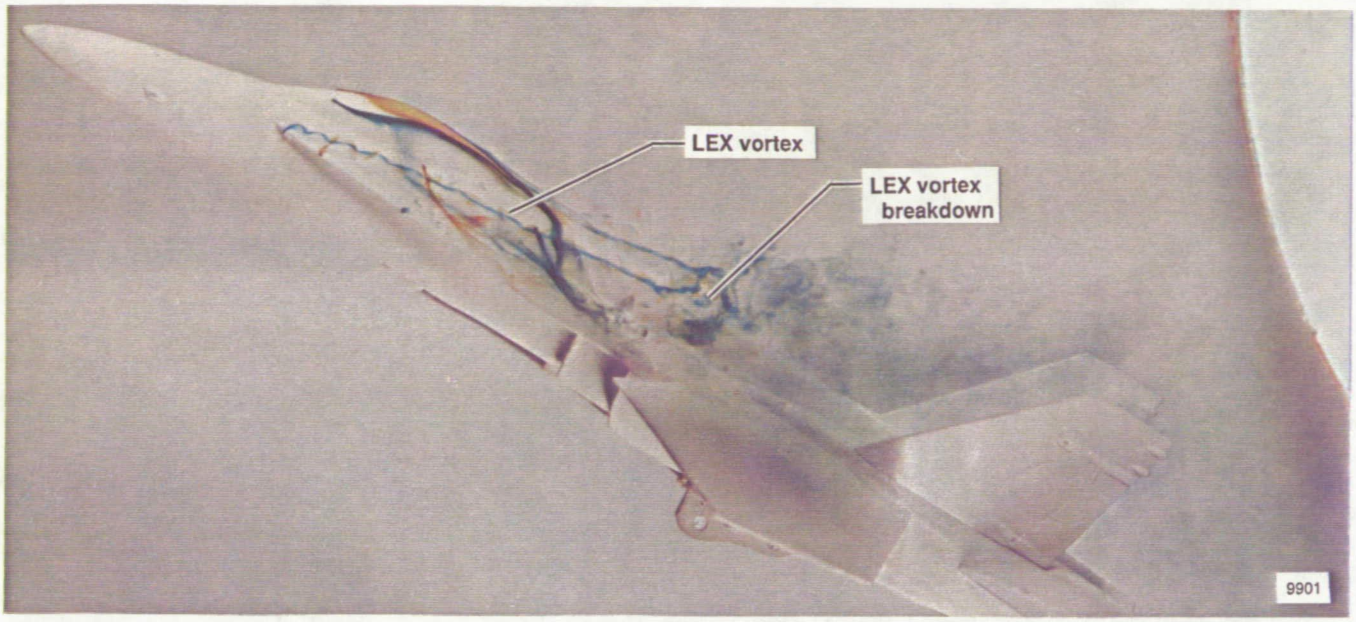
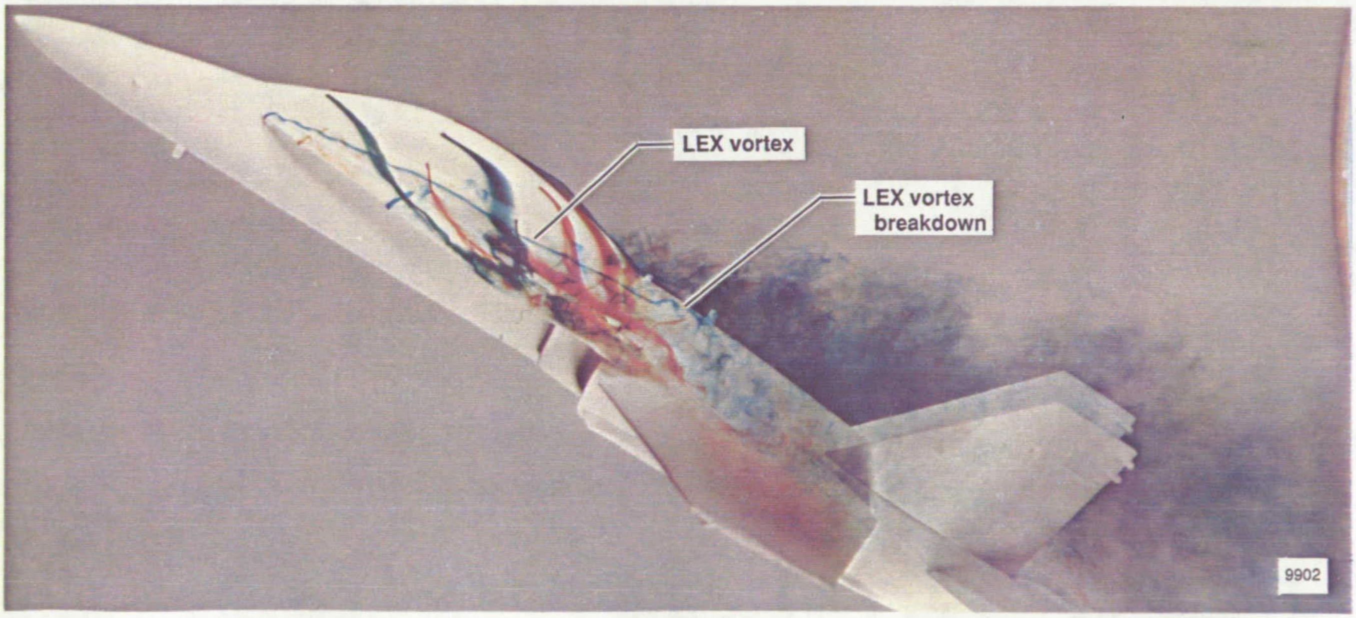


Figure 3. Water-tunnel flow visualization of forebody vortex-LEX vortex flow interaction; $\alpha = 32°$, $\beta = 0°$.

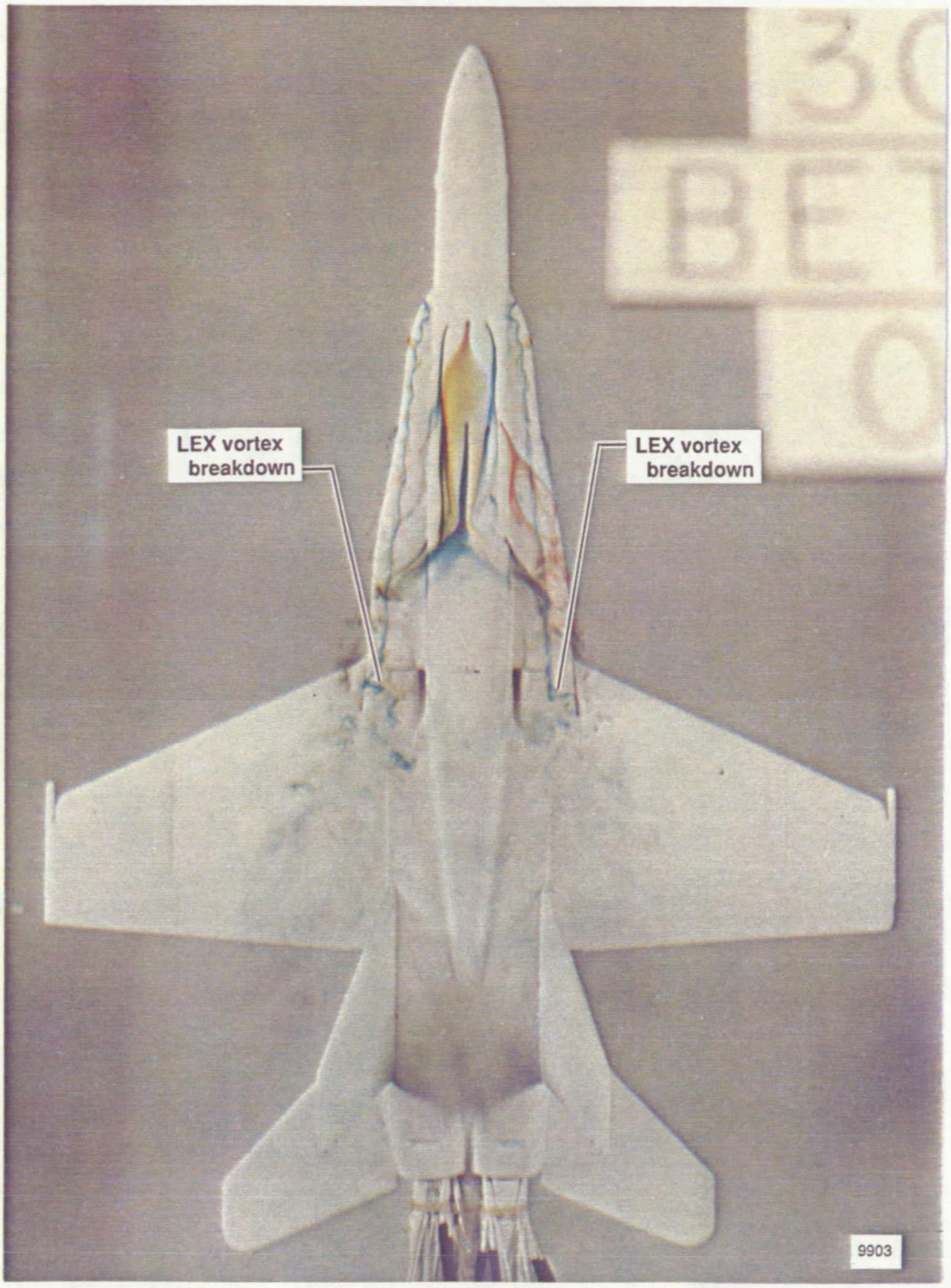


(a) F/A-18.



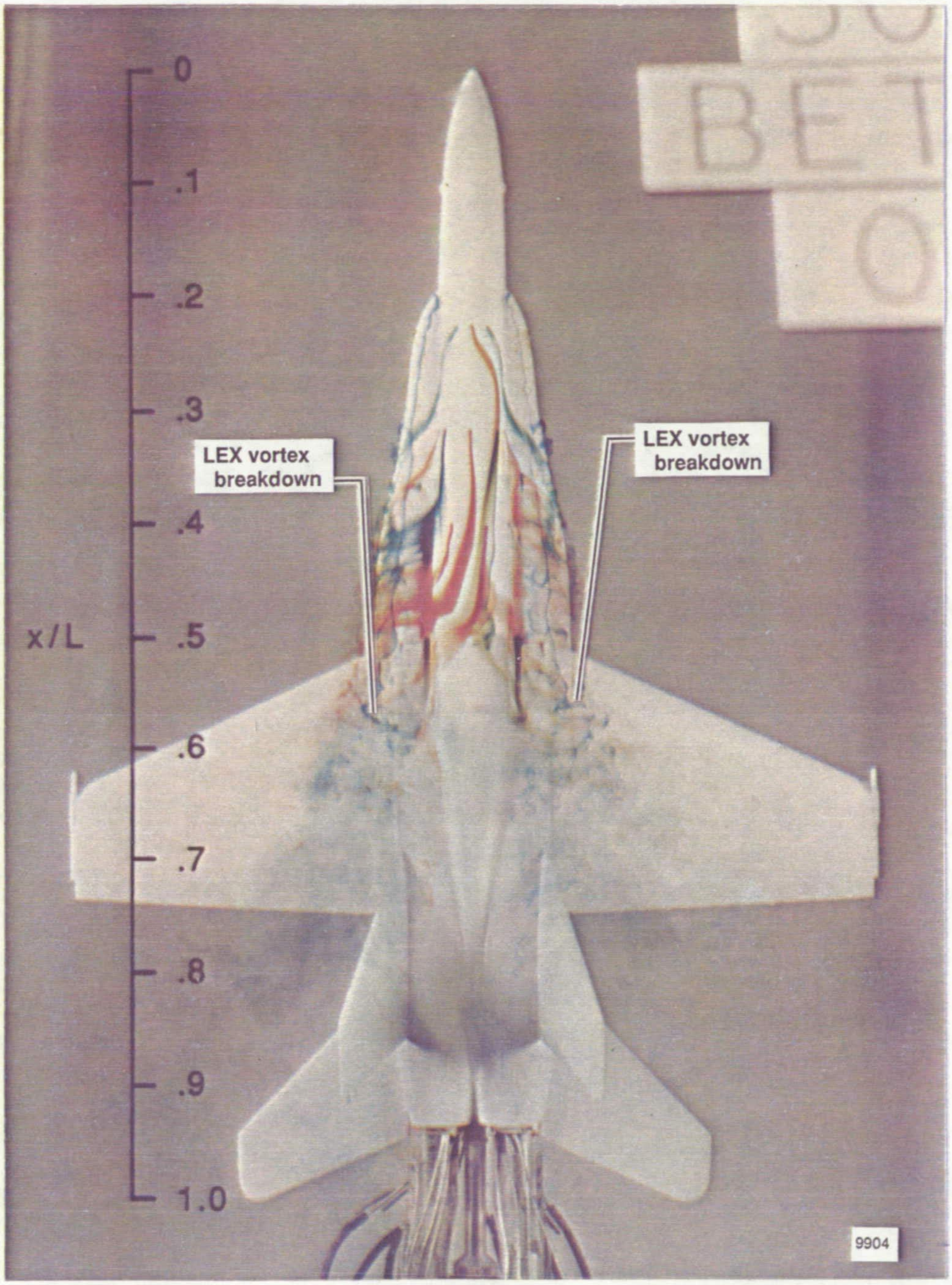
(b) TF/A-18.

Figure 4. Side view of model at $\alpha = 30°$, $\beta = 0°$.



(a) F/A-18.

Figure 5. Plan view of model at $\alpha = 30°$, $\beta = 0°$.



(b) TF/A-18.

Figure 5. Concluded.

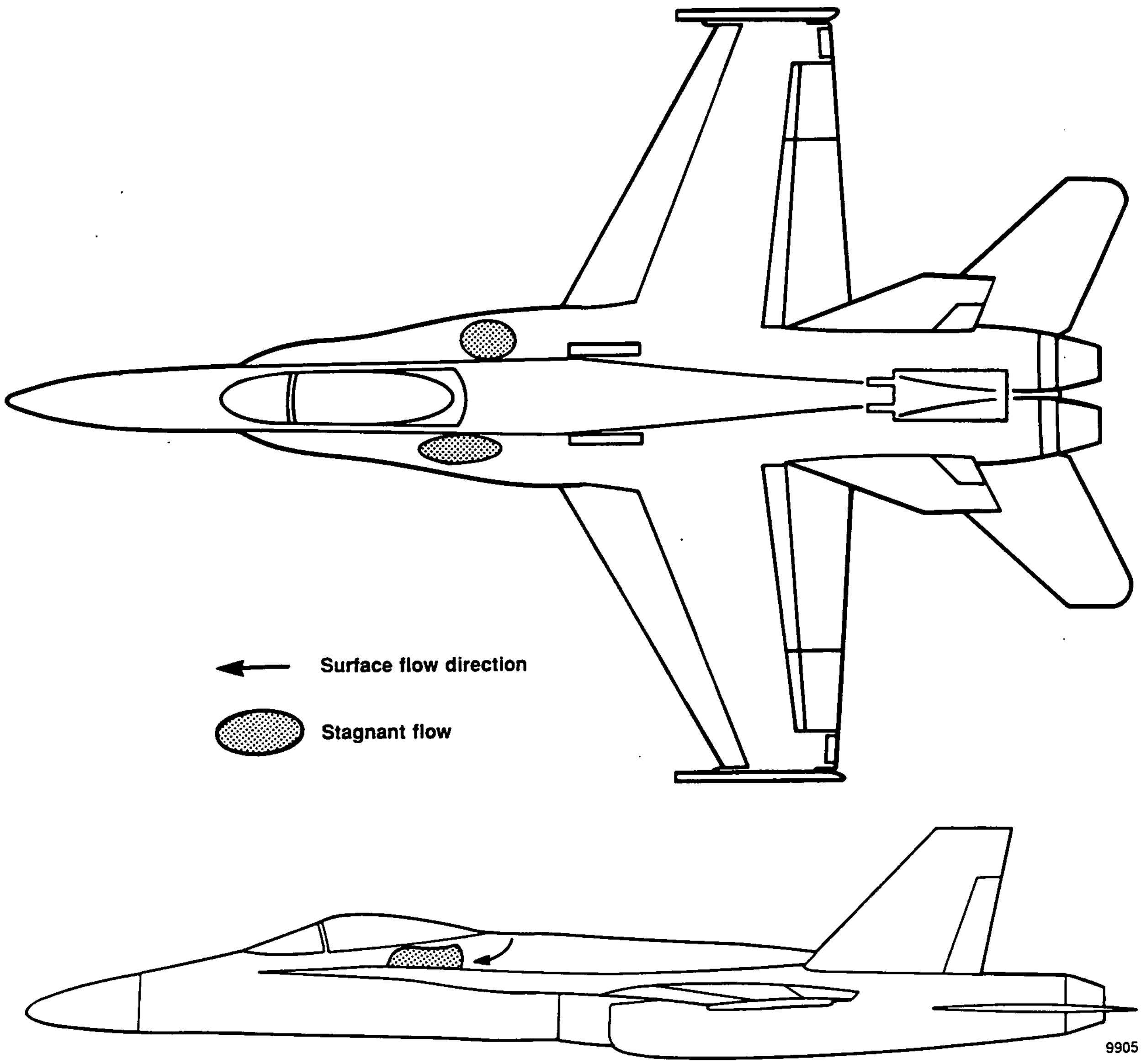


Figure 6. F/A-18 LEX and fuselage flow detail; $\alpha = 30°$, $\beta = 0°$.

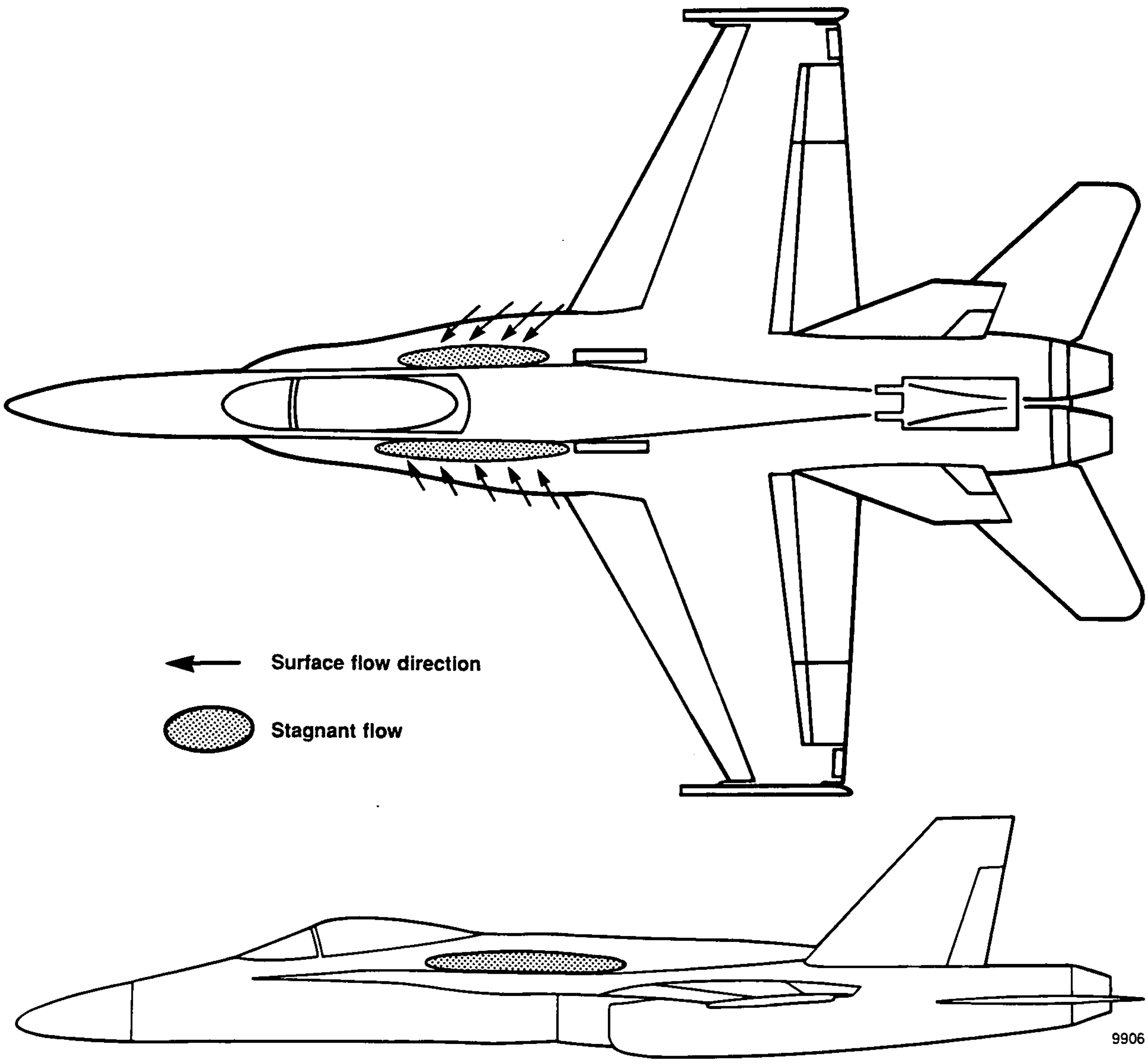
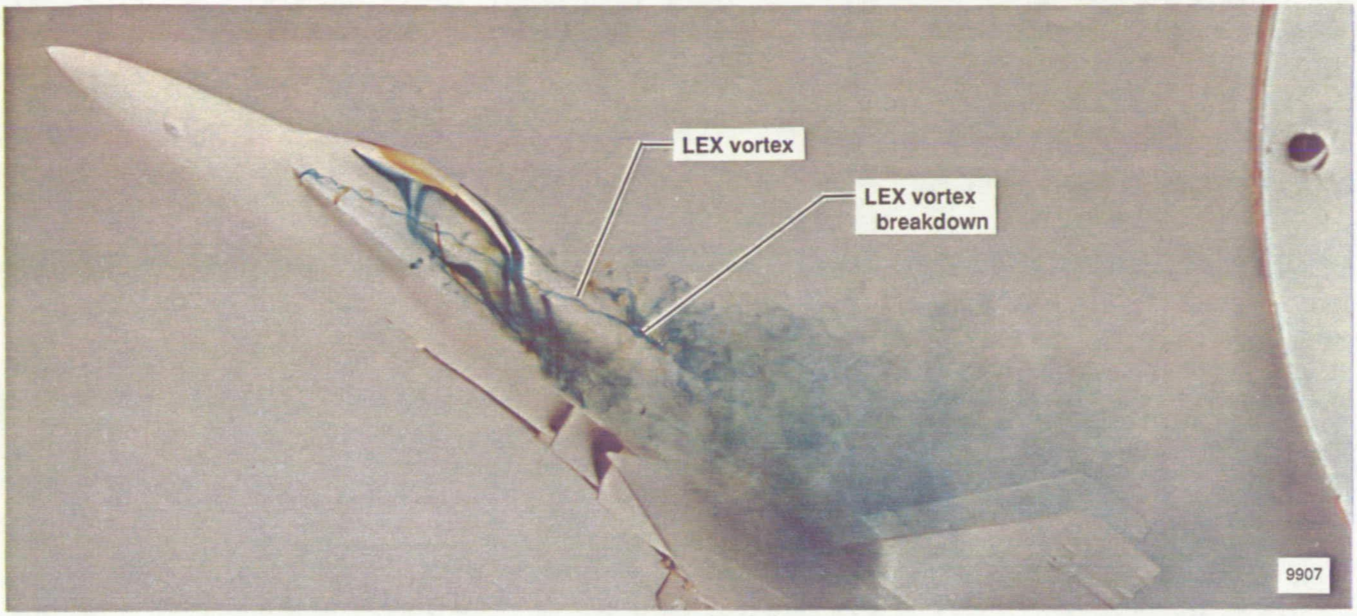
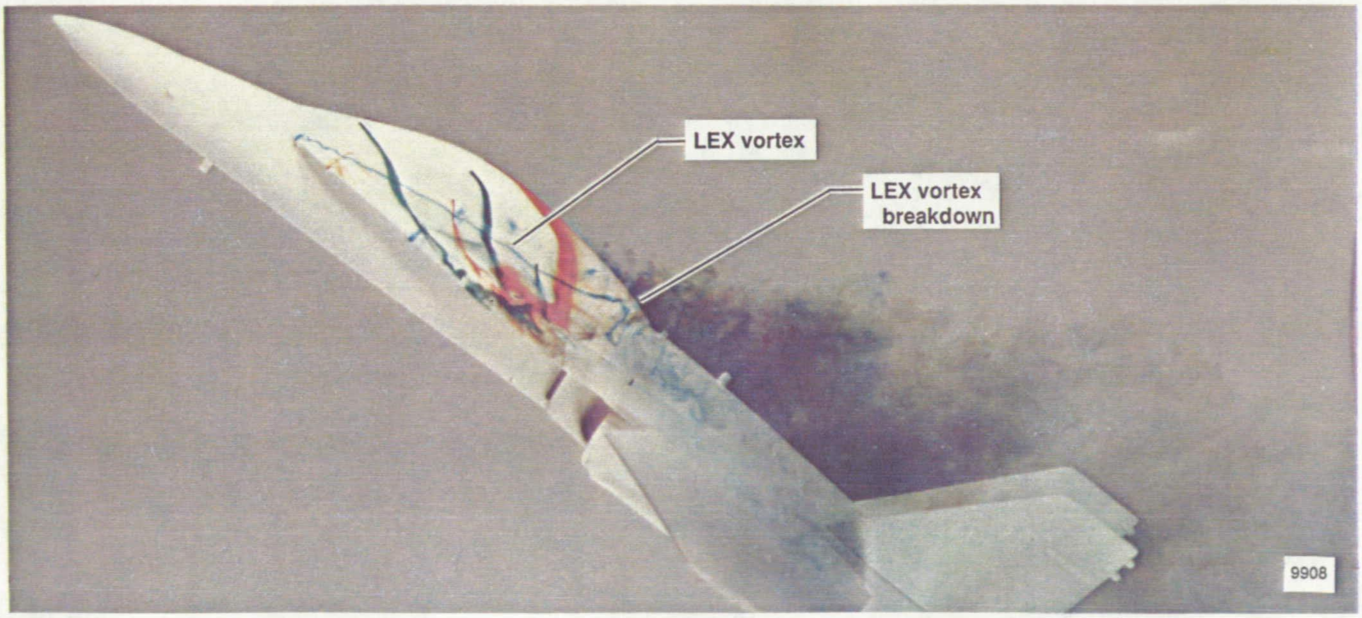


Figure 7. TF/A-18 LEX and fuselage flow detail; $\alpha = 30°$, $\beta = 0°$.



(a) F/A-18.



(b) TF/A-18.

Figure 8. Side view of model at $\alpha = 35°$, $\beta = 0°$.

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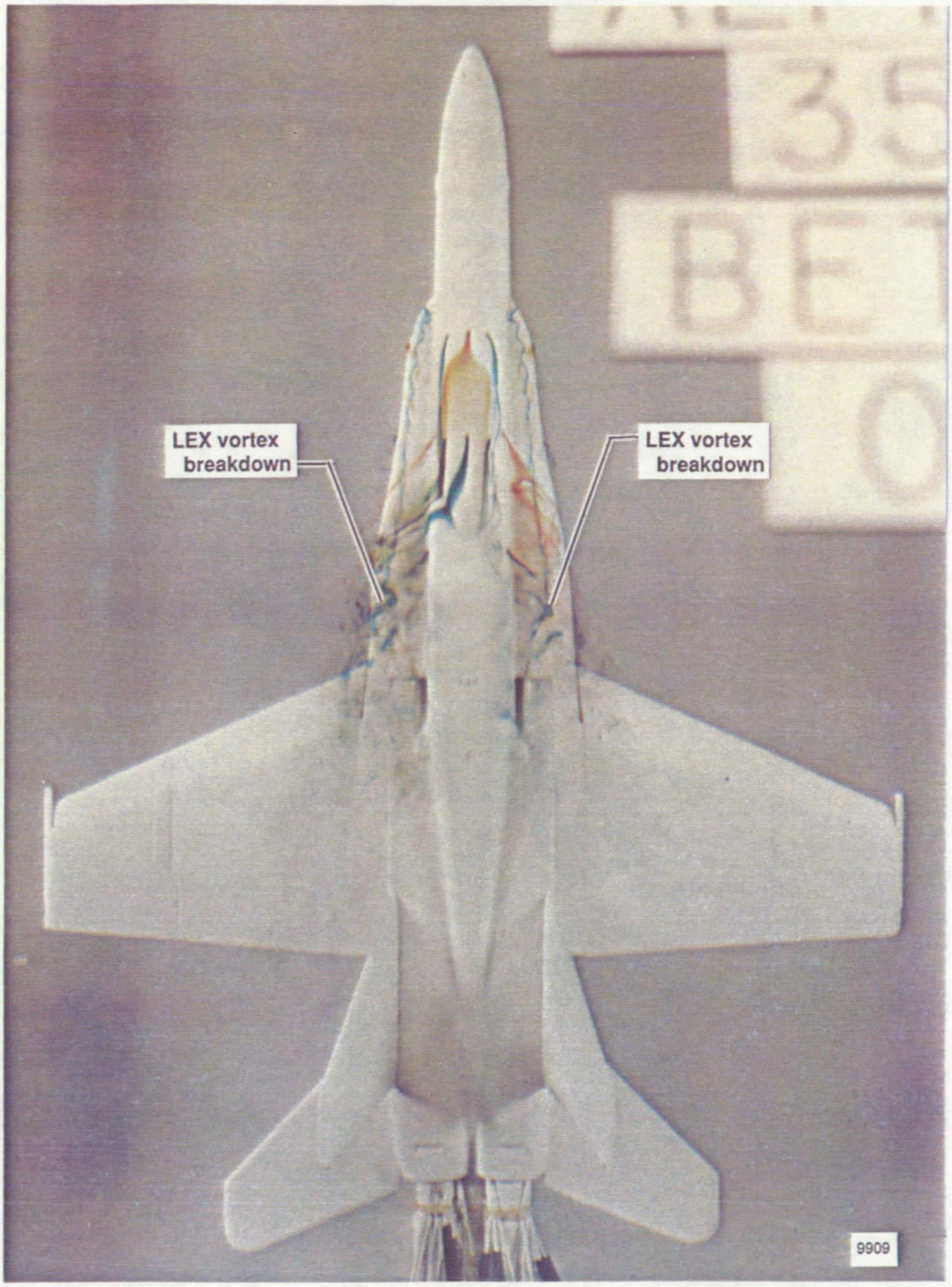

(a) F/A-18.

Figure 9. Plan view of model at $\alpha = 35°$, $\beta = 0°$.

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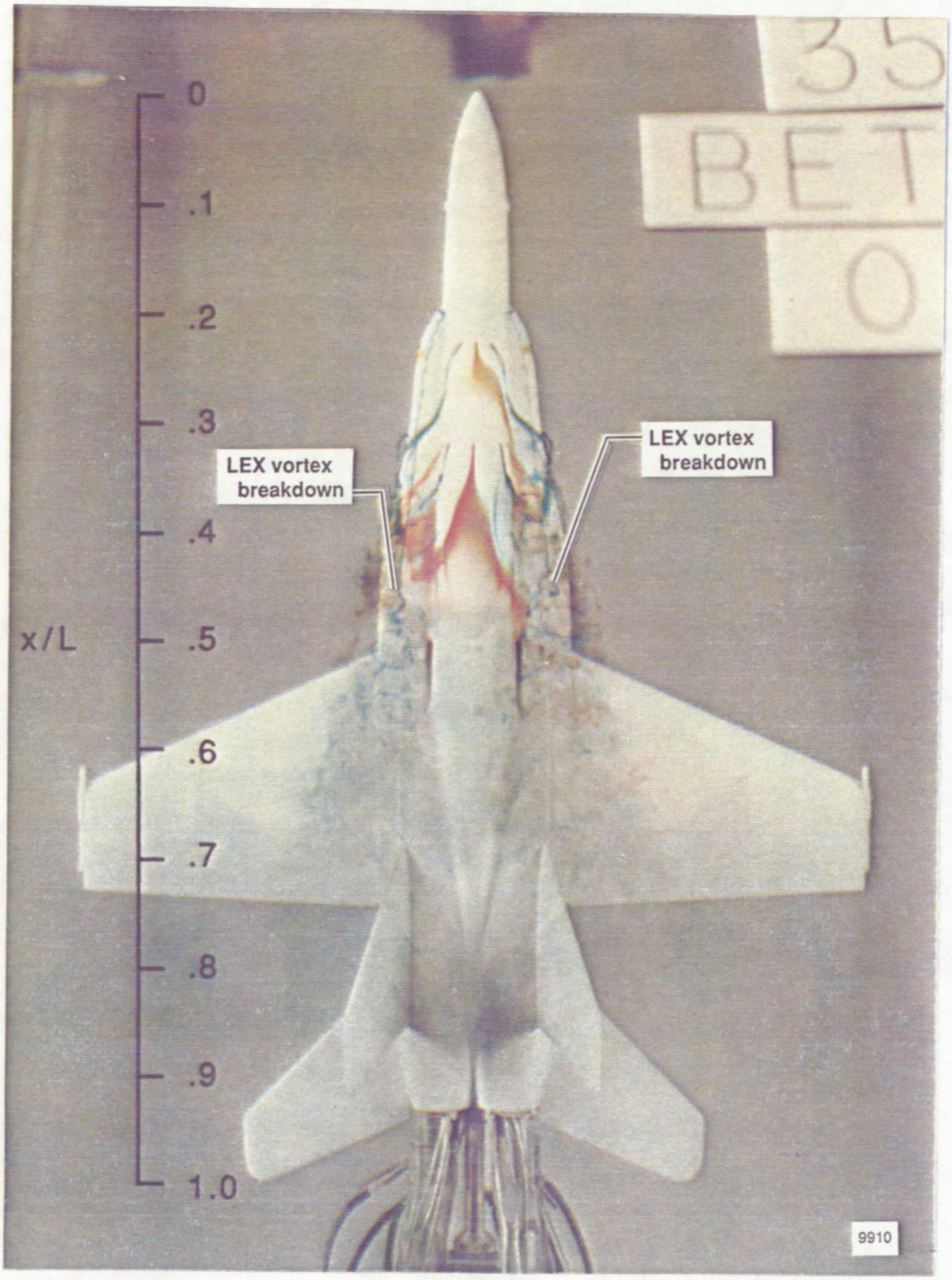


(b) TF/A-18.

Figure 9. Concluded.

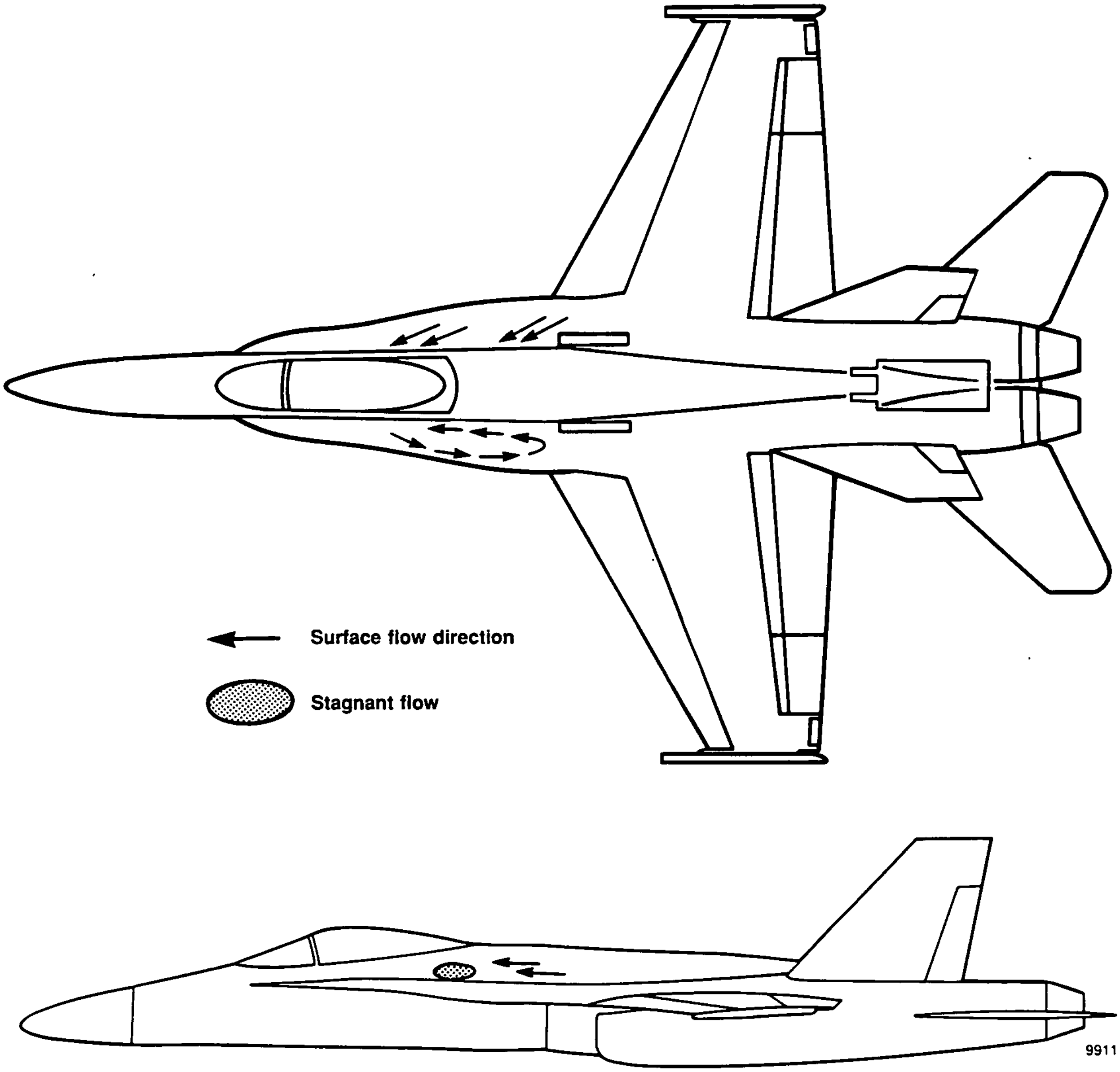


Figure 10. F/A-18 LEX and fuselage flow detail; $\alpha = 35°$, $\beta = 0°$.

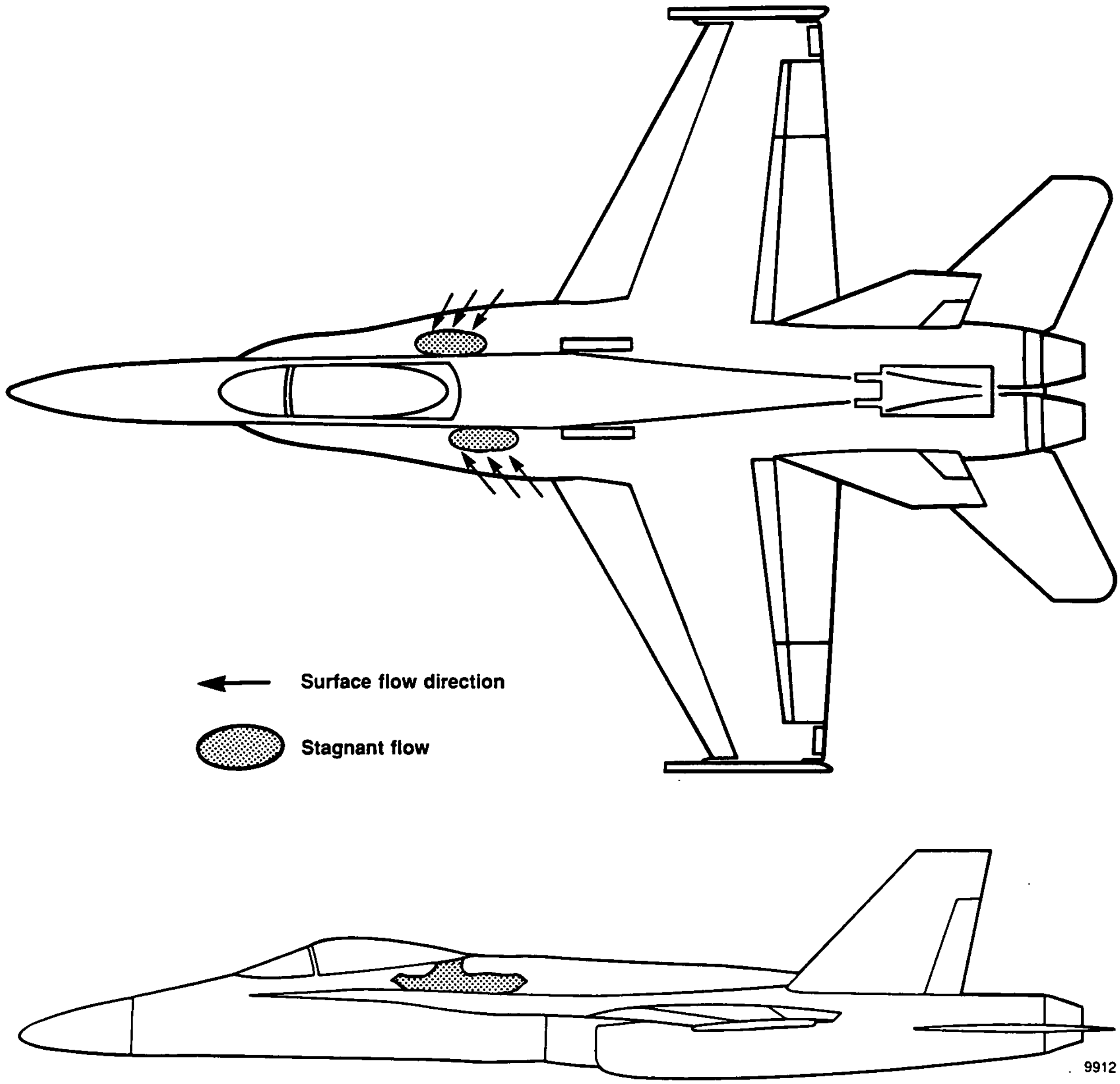
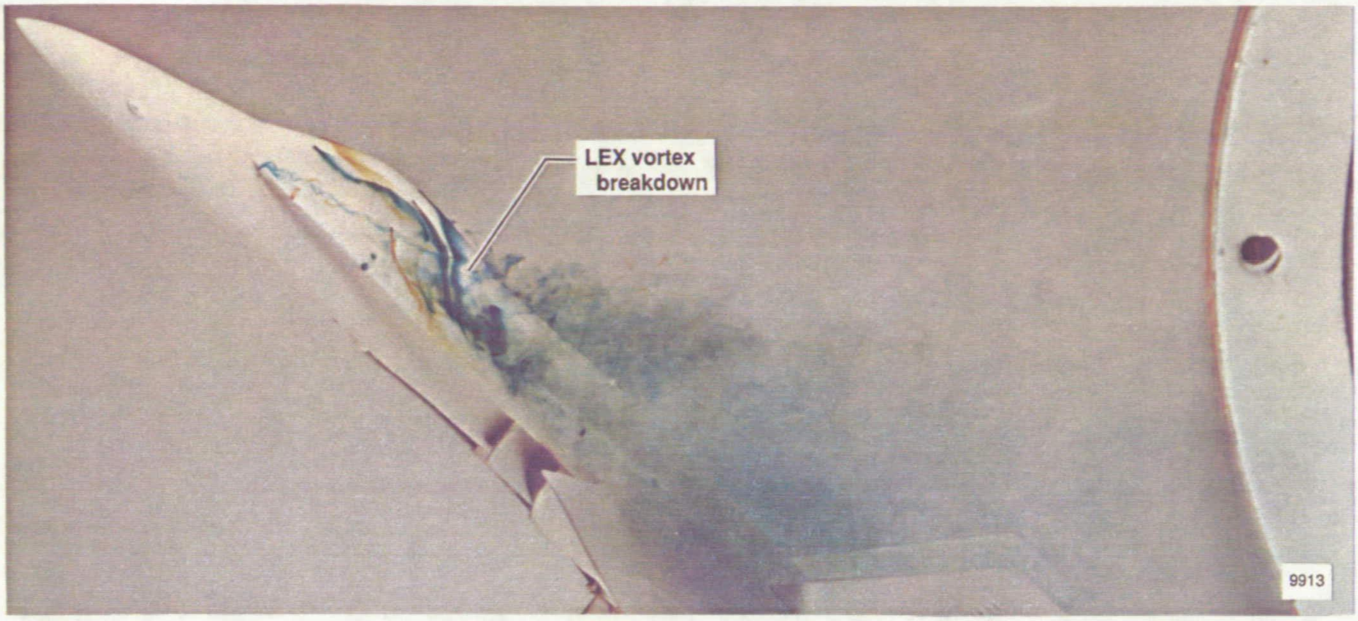
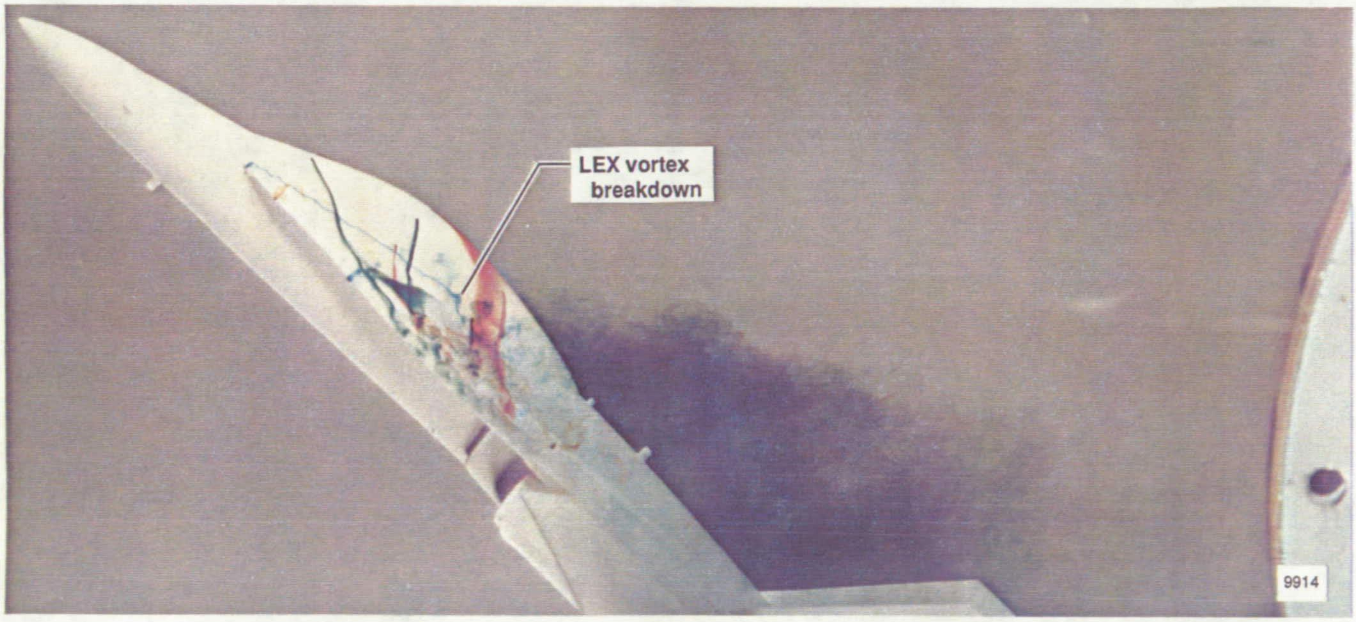


Figure 11. TF/A-18 LEX and fuselage flow detail; $\alpha = 35°$, $\beta = 0°$.

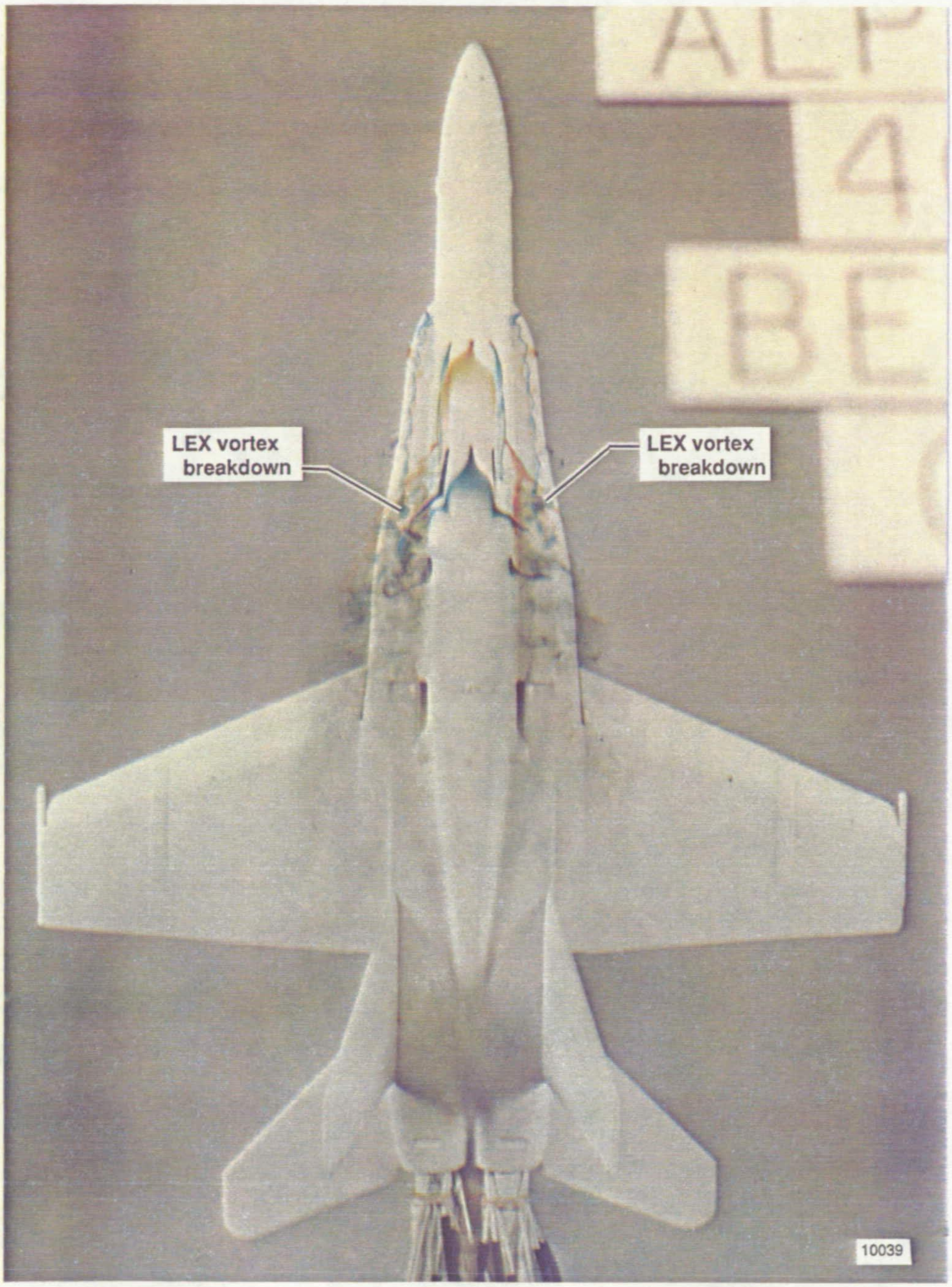


(a) F/A-18.



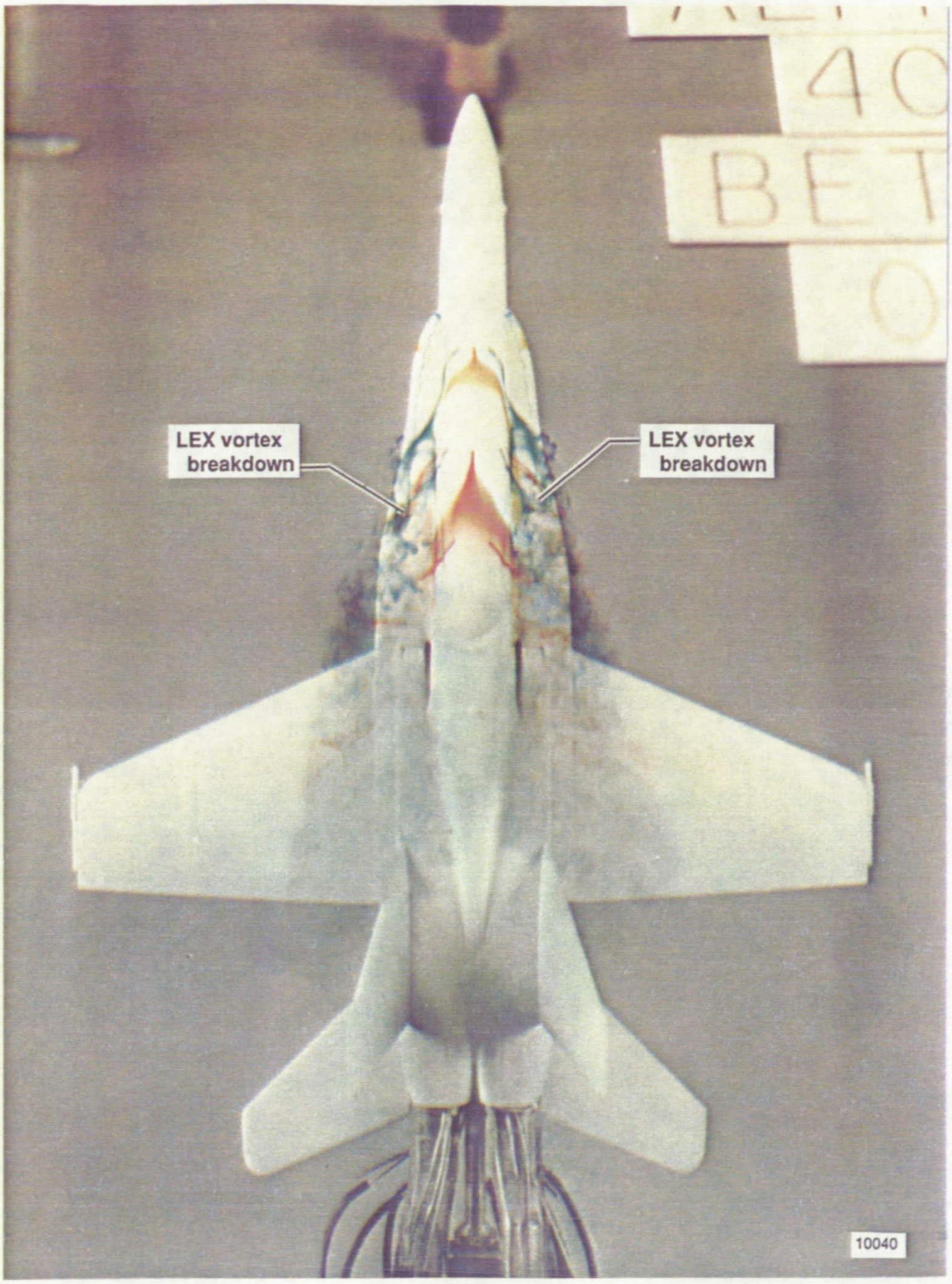
(b) TF/A-18.

Figure 12. Side view of model at $\alpha = 40°$, $\beta = 0°$.



(a) F/A-18.

Figure 13. Plan view of model at $\alpha = 40°$, $\beta = 0°$.



(b) TF/A-18.

Figure 13. Concluded.

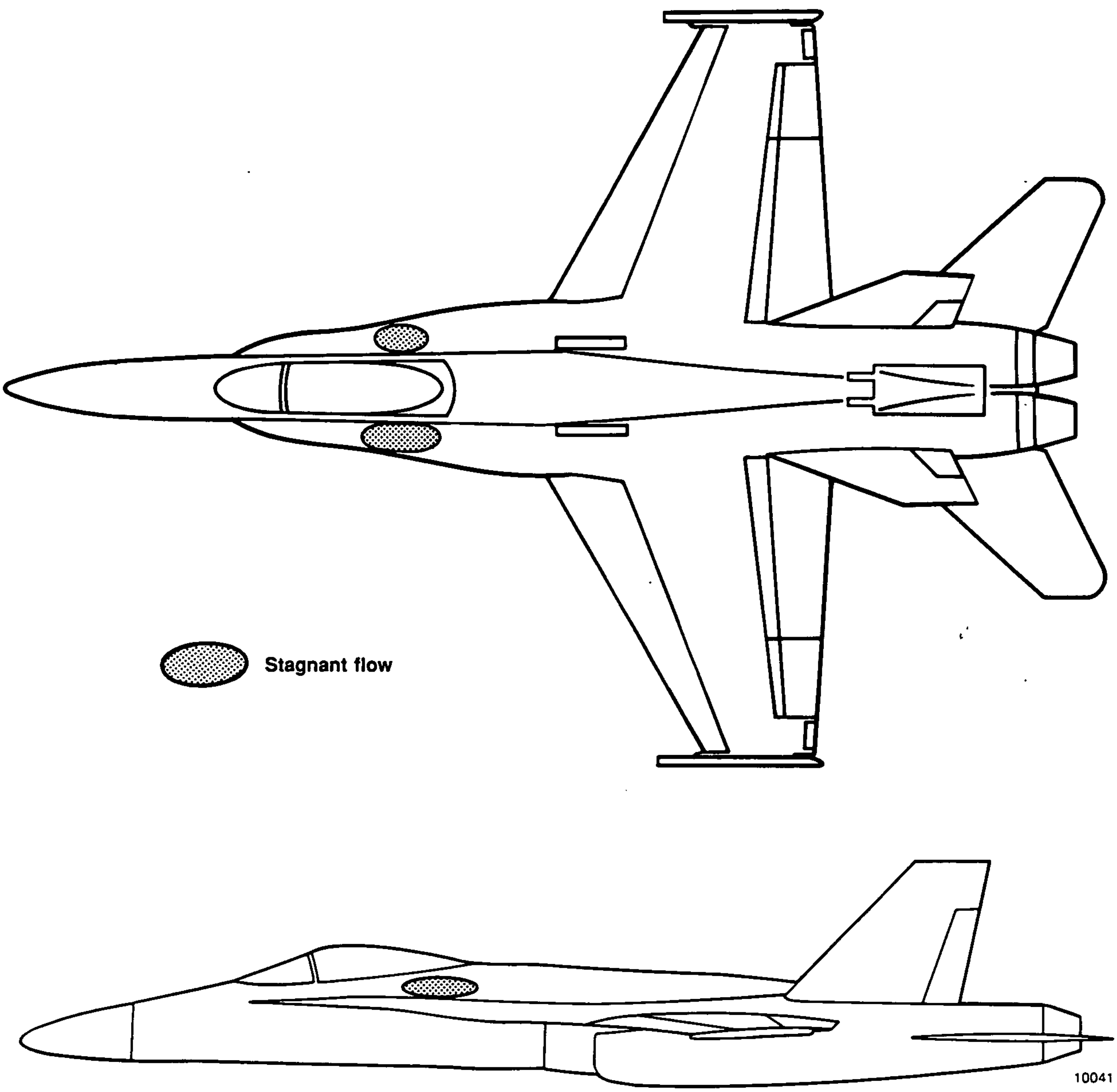


Figure 14. F/A-18 LEX and fuselage flow detail; $\alpha = 40°$, $\beta = 0°$.

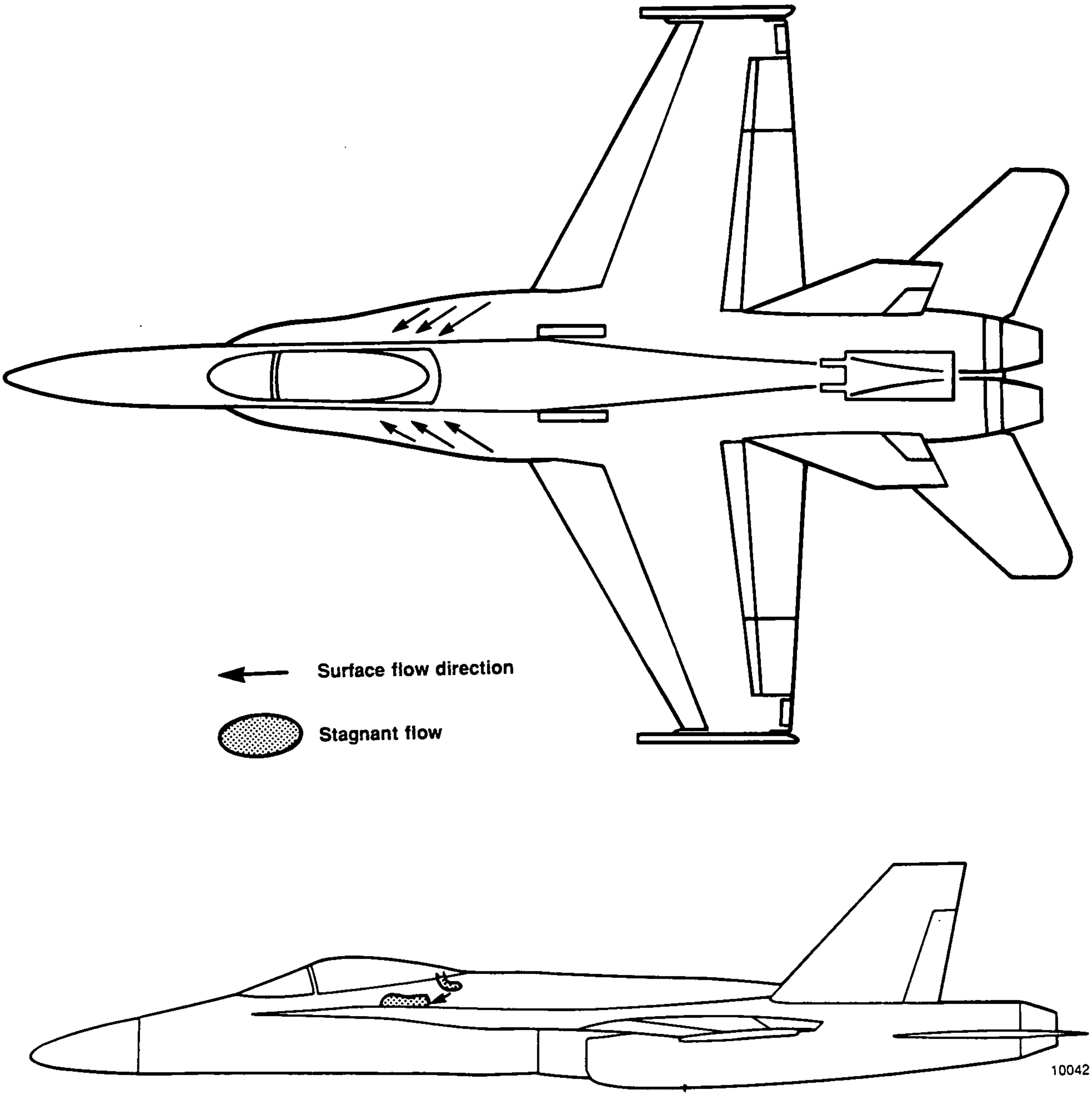
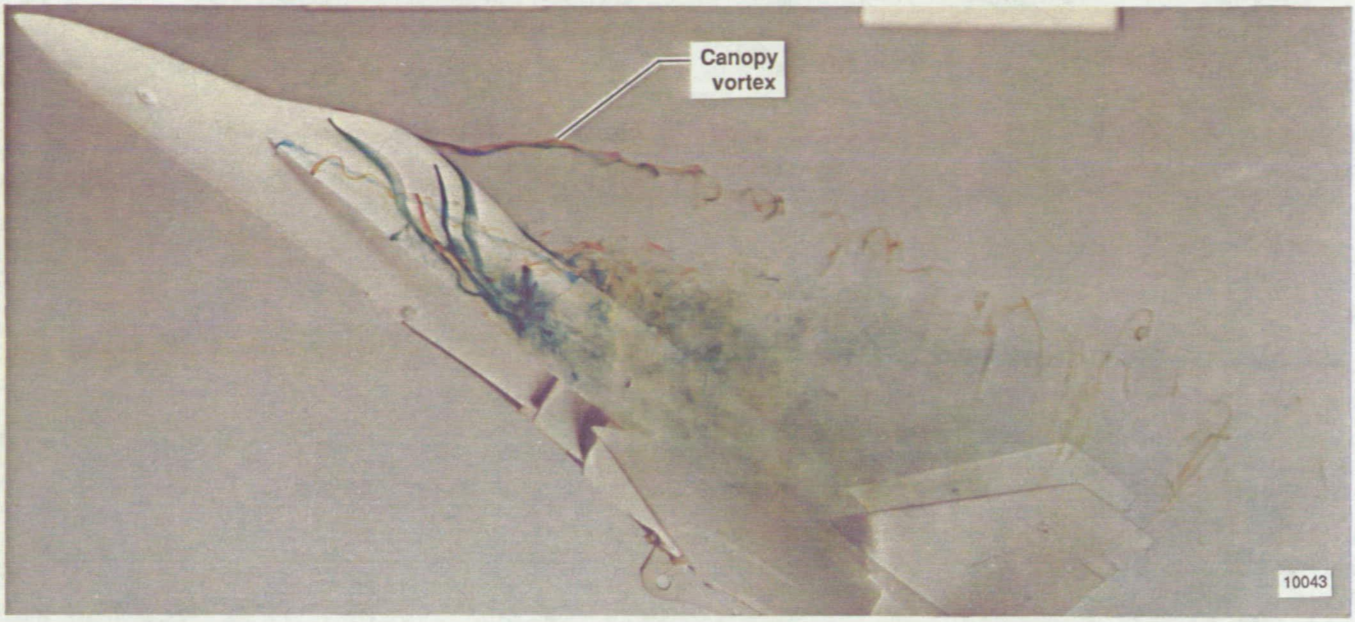
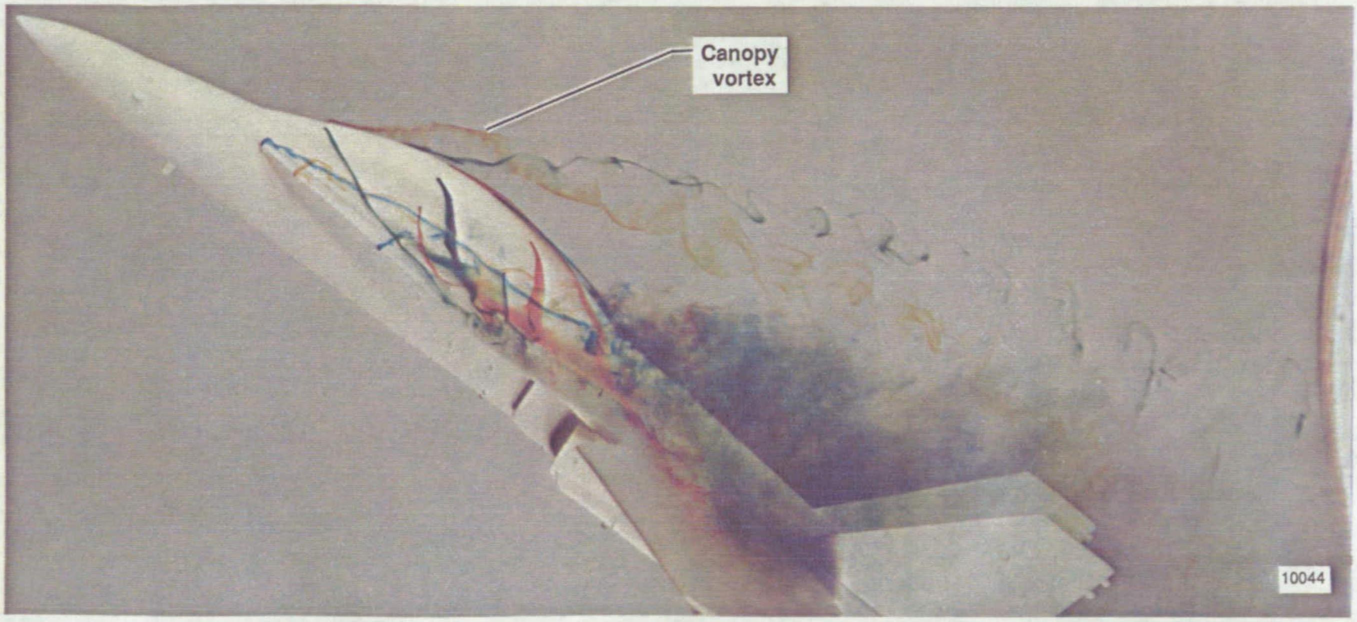


Figure 15. TF/A-18 LEX and fuselage flow detail; $\alpha = 40°$, $\beta = 0°$.

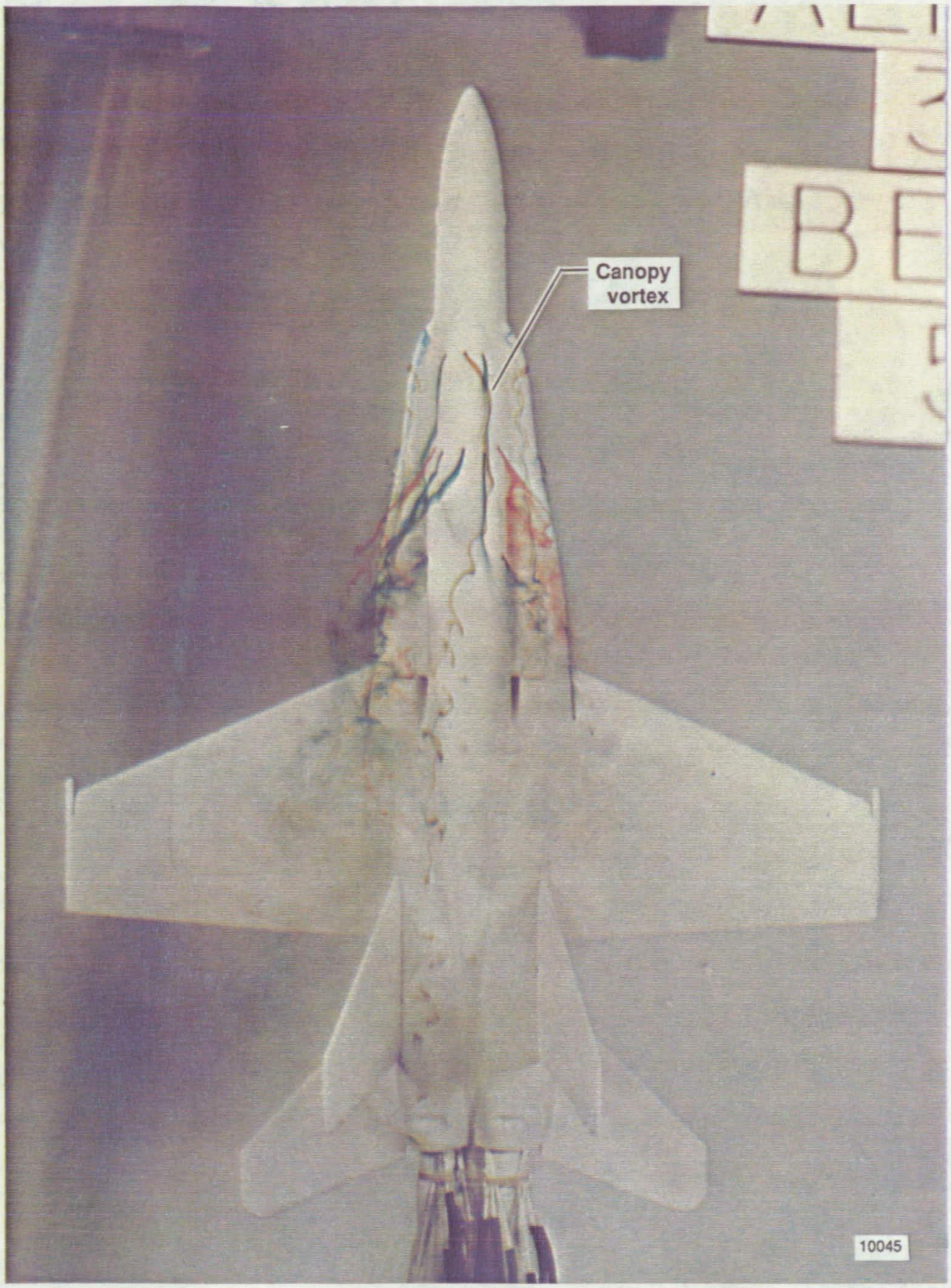


(a) F/A-18.



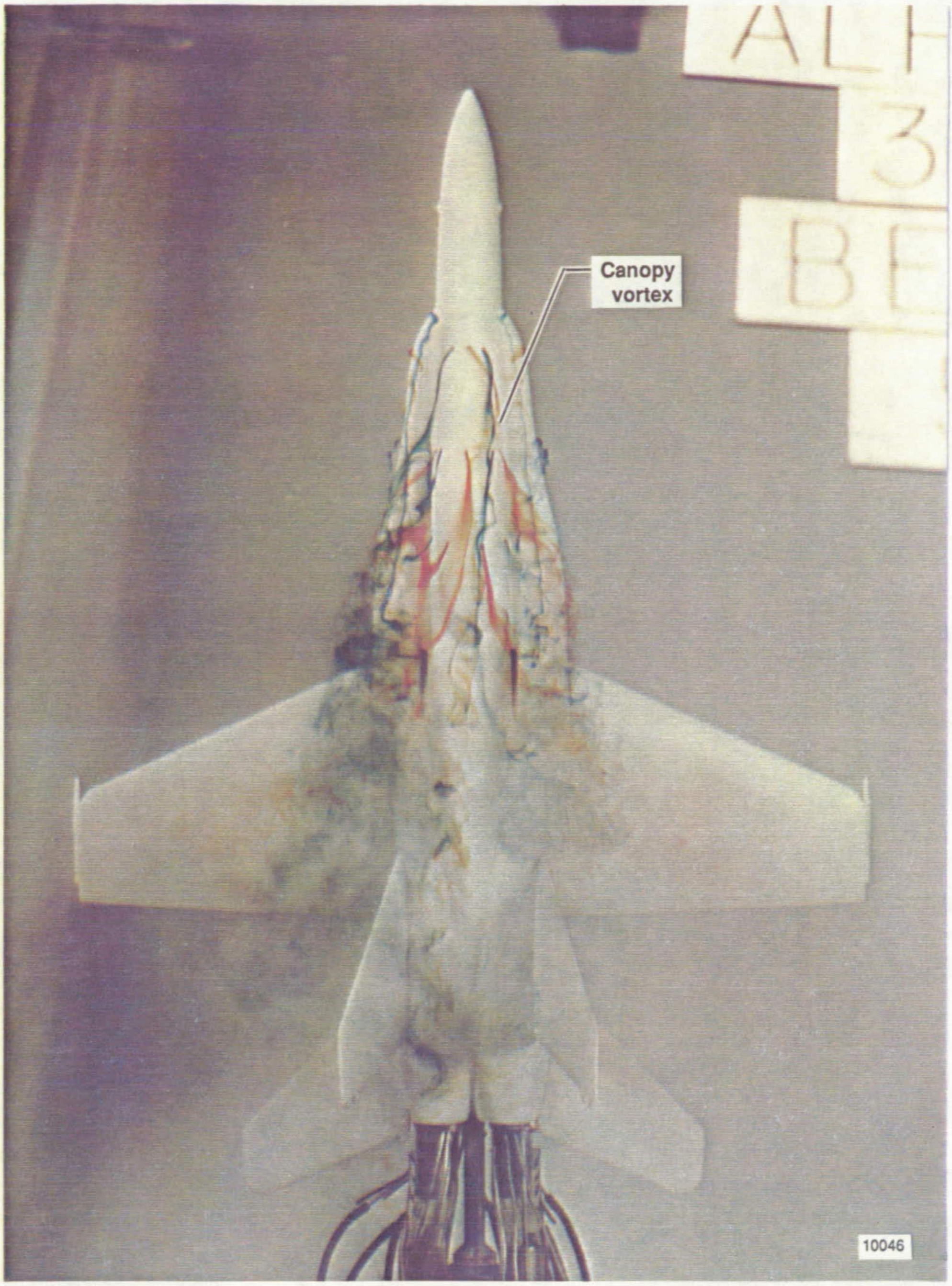
(b) TF/A-18.

Figure 16. Side view of model at $\alpha = 35^\circ$, $\beta = 5^\circ$.



(a) F/A-18.

Figure 17. Plan view of model at $\alpha = 35°$, $\beta = 5°$.



(b) TF/A-18.

Figure 17. Concluded.

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15. Supplementary Notes

16. Abstract

A water-tunnel study examining the influence of canopy shape on canopy and leading-edge extension flow patterns was initiated at the NASA Ames-Dryden Flow Visualization Facility. The F/A-18 single-place canopy model and the TF/A-18 two-place canopy model were the study subjects. Plan view and side view photographs showing the flow patterns created by injected colored dye are presented for 0° and 5° sideslip angles. Photographs taken at angle-of-attack and sideslip conditions correspond to test departure points found in flight test. Flight experience has shown that the TF/A-18 airplane departs in regions where the F/A-18 airplane is departure-resistant. The study results provide insight into the differences in flow patterns which may influence the resulting aerodynamics of the TF/A-18 and F/A-18 aircraft. It was found that at 0° sideslip, the TF/A-18 model has more downward flow on the sides of the canopy than the F/A-18 model. This could be indicative of flow from the leading-edge extension (LEX) vortexes impinging on the sides of the wider TF/A-18 canopy. In addition, the TF/A-18 model has larger areas of asymmetric separated and unsteady flow on the LEXs and fuselage, possibly indicating a lateral and directional destabilizing effect at the conditions studied.

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