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# An Oil Flow Study of the Reference Shuttle-C Configuration

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## ACKNOWLEDGMENTS

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REFERENCE PUBLICATION

# AN OIL FLOW STUDY OF THE REFERENCE SHUTTLE-C CONFIGURATION

## I. INTRODUCTION

This report documents the oil flow studies done on a typical sidemounted vehicle configuration. The purpose of flow visualization is to make flow visible which otherwise is nonvisible. An oil flow is one technique that allows attached flow as well as flow characterized by different types of separation to become visible. It is especially useful in the determination of flow phenomenon around a multibody vehicle to determine the flow regime between the bodies. The Shuttle-C configuration is a multibodied sidemounted configuration, like the space shuttle. This type of configuration results in significant interactions between the elements and components. These interactions can be seen in the oil flows, especially the bottom view of the cargo carrier (CC) and the top view of the lower stack (LS). These results would be difficult to analytically determine without the use of a flow visualization technique such as the oil flow.

This report presents oil flows of the proposed Shuttle-C reference configuration. The oil flows were taken over the Mach range of 1.10 to 3.48, at angles-of-attack of 0°. At Mach = 3.48, oil flows were also taken at angles-of-attack of –4° and at angles-of-sideslip of 4°. These oil flows present a pictorial view of the surface flow fields over the Shuttle-C configuration. This configuration was tested in the Marshall Space Flight Center's 14-Inch Trisonic Wind Tunnel over the period of October 1988 to February 1989.[1]

This report presents oil flows for the Shuttle-C vehicle in a concise format, is a means of easy transfer of the data to interested parties, and also documents the results for future study.

## II. MODEL AND FACILITY DESCRIPTION

### A. Facility Description

The MSFC 14- by 14-Inch Trisonic Wind Tunnel (TWT) is an intermittent blowdown tunnel which operates by high pressure air flowing from storage to either vacuum or atmosphere conditions. The transonic test section provides a Mach number range from 0.2 to 2.0. A solid wall supersonic test section provides the entire range from 2.74 to 5.0 with one set of automatically actuated contour blocks. Downstream of the test section is a hydraulically controlled pitch sector that provides the capability of testing up to 20 angles-of-attack from –10° to +10° during each run. Sting offsets are available for obtaining various maximum angels-of-attack up to 90°. This is further detailed in reference 2. The MSFC 14- by 14-Inch TWT facility is shown in figure 1.

### B. Model Description

The 0.004 scale Shuttle-C reference configuration model consisted of a CC mated to the Space Transportation System (STS) LS which consists of an external tank (ET) with two solid rocket boosters (SRB's). The model is a representation of the Shuttle-C sidemount reference configuration concept studied. This configuration includes a CC which has a cylindrical forward body of 82 ft in length and 18.3 ft (full scale) in diameter with an STS boattail. The nose is a 26.5° half angle nose cone that was blunted with a nose radius of 3.542 ft (full scale). The orbital maneuvering subsystem (OMS) pods were mounted in the same relative position as they are on the STS orbiter. Figure 2 shows the reference configuration mounted in the 14- by 14-Inch TWT.

## III. OIL FLOW DESCRIPTION

"Since many years of wind tunnel practice the surface oil film technique is taken as a standard technique for experimentation (Maltby, 1962). This technique serves for visualizing the flow pattern close to the surface of a solid body exposed to an air flow."[3] The oil flow is a flow visualization technique that is used to define the boundary layer transition locations, shock impingement points, and flow separation and reattachment.

The procedure for acquiring oil flows in the MSFC's 14-Inch TWT is described as follows. The model is installed on a "dummy" balance and sting. The model surface is then painted with a white paint to provide a contrasting background. A mixture of light weight oil and blue or red permanent artists' oil color is dabbed on the model with a brush providing a speckling-type effect.

The particular test conditions (Mach number, angle-of-attack, model configuration) are set up and run. The resulting streaks on the model show the direction of the surface streamlines. The streak pattern also shows regions of separated flow, if and where reattachment occurs, and provides other valuable external flow information. The model is removed from the tunnel and photographs are taken of the flow patterns produced.

For the Shuttle-C vehicle, a series of photographs were taken. Mated vehicle pictures were taken of the model rotated at 45° increments. The model was then disassembled into CC and LS elements. The bottom of the CC was photographed to show flow interaction between the CC and LS. The LS was photographed at rotations of 0°, 45°, and 90°. This set of oil flows provides a spectrum of viewing areas of the vehicle at various flow conditions.

## IV. OIL FLOW EVALUATION

Figure 3 is a typical oil flow. This oil flow shows the Shuttle-C mated vehicle configuration rotated 135° tested at an alpha = 0° and a beta = 0° at a Mach of 1.46. This photograph shows the surface streamlines along the bodies. Geometry and protuberance effects can also be seen. Various flow phenomena, such as turbulent flow, flow expansion, recirculation, flow separation, flow reattachment, shock impingement, and vertical flow are labeled. The oil flows taken at other test conditions show similar traits. The complete set of oil flows is shown in figures 4 through 95.

## V. CONCLUSIONS

Using the oil flows, a qualitative understanding of the flow around the vehicle can be determined, aiding in the quantitative definition of aerodynamic data from theoretical analyses and test results.

Oil flows are presented over a range of Mach numbers for the Shuttle-C reference configuration. The oil flows show the effects of Mach number in the transonic/supersonic Mach range, angle of attack, and angle of sideslip on the vehicle. As the Mach number increases, the flow fields become more pronounced. The interaction between the CC and LS changes over the Mach range and can be seen in the oil flows. The vortex due to CC interaction with the SRB's, seen on the ET, moves aft along the ET as the Mach number increases.

The oil flows taken at Mach 3.48 varying the angle-of-attack, show only slight differences in the flow characteristics along the vehicle. There appears to be no significant difference in flow fields along the body for these variations in angles-of-attack.

## REFERENCES

1. Pokora, Darlene C.: "Posttest Report for the Shuttle-C Test in the MSFC 14-Inch Trisonic Wind Tunnel (TWT 715)." ED35-17-89, February 28, 1989.

2. Simon, E.H.: "The George C Marshall Space Flight Center's 14×14 Inch Trisonic Wind Tunnel Technical Handbook." NASA TMX-64624, November 5, 1971.

3. Merzkirch, W.: "Flow Visualization." Second Edition, 1987, Academic Press, Inc., Chapter 2.4 Visualization of Surface Flow, p.82.


Figure 1. NASA MSFC's 14- by 14-in trisonic wind tunnel.

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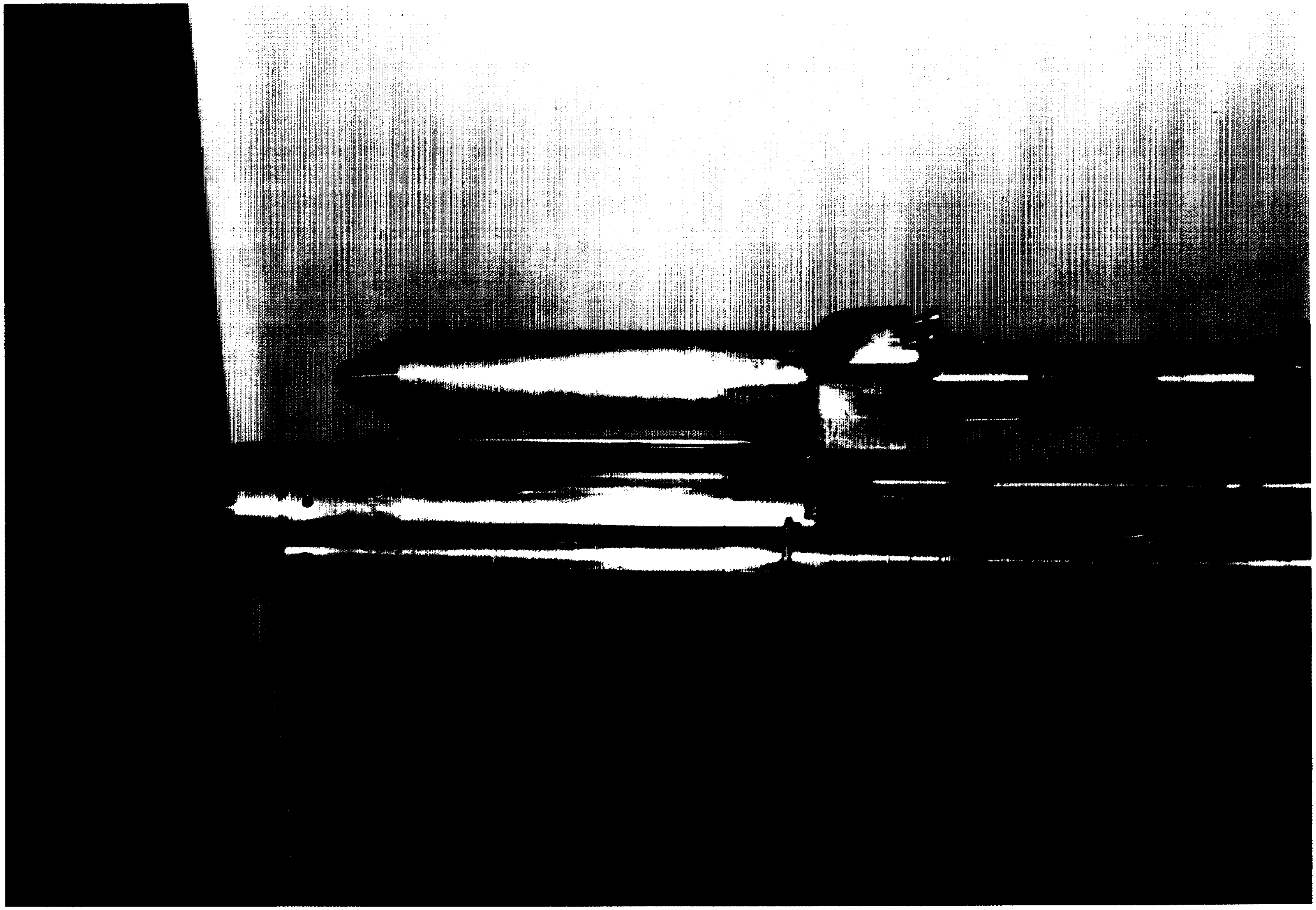
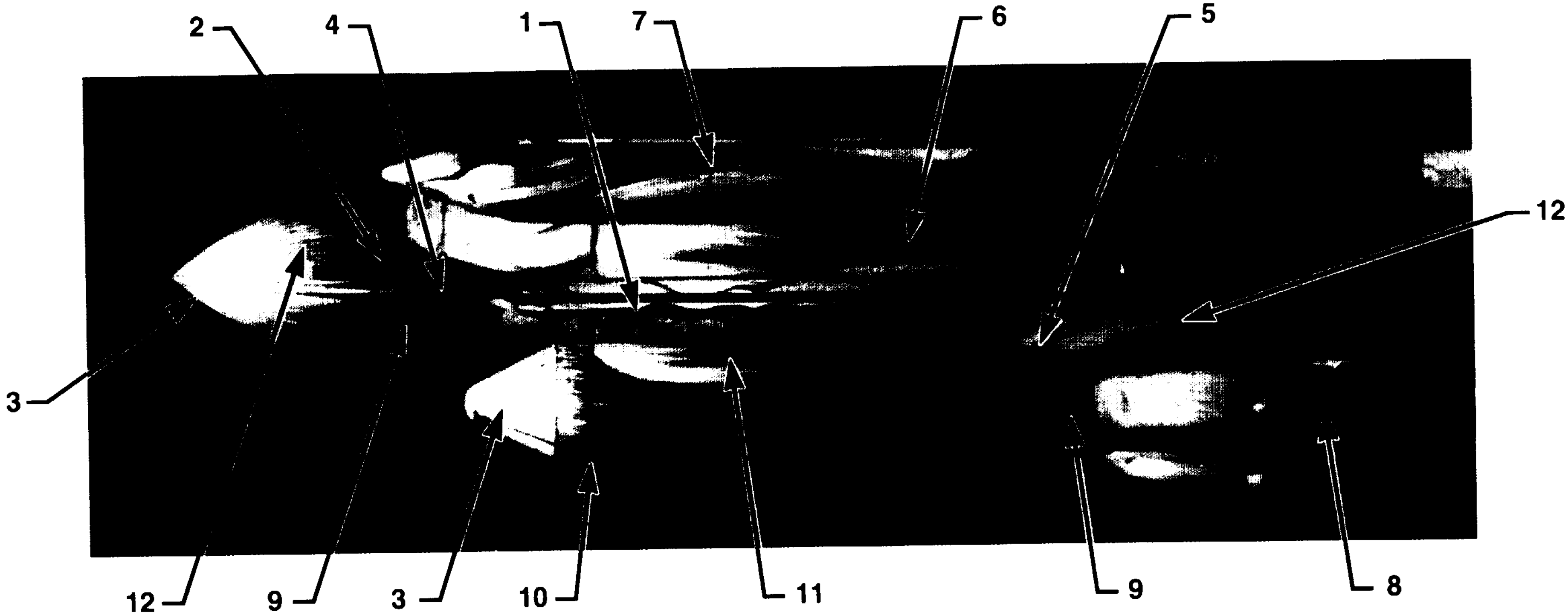


Figure 2. Shuttle-C reference configuration installed in the MSFC 14-in wind tunnel.




1 Attach strut interference separation

2 Flow separation due to bow shock/ boundary layer interaction

3 High pressure

4 Shock impingement of CC on ET

5 Dividing streamline of flow passing over and beneath OMS pods

6 Turbulent flow

7 Cross flow due to impingement of CC nose shock

8 Recirculation in base region

9 Flow separation due to shock and circulating flow region

10 Model seam not totally flush

11 Impingement region of SRB nose shock

12 Attached flow

Figure 3. Reference Configuration Mach 1.46, alpha = 0, beta = 0, phi = 135.

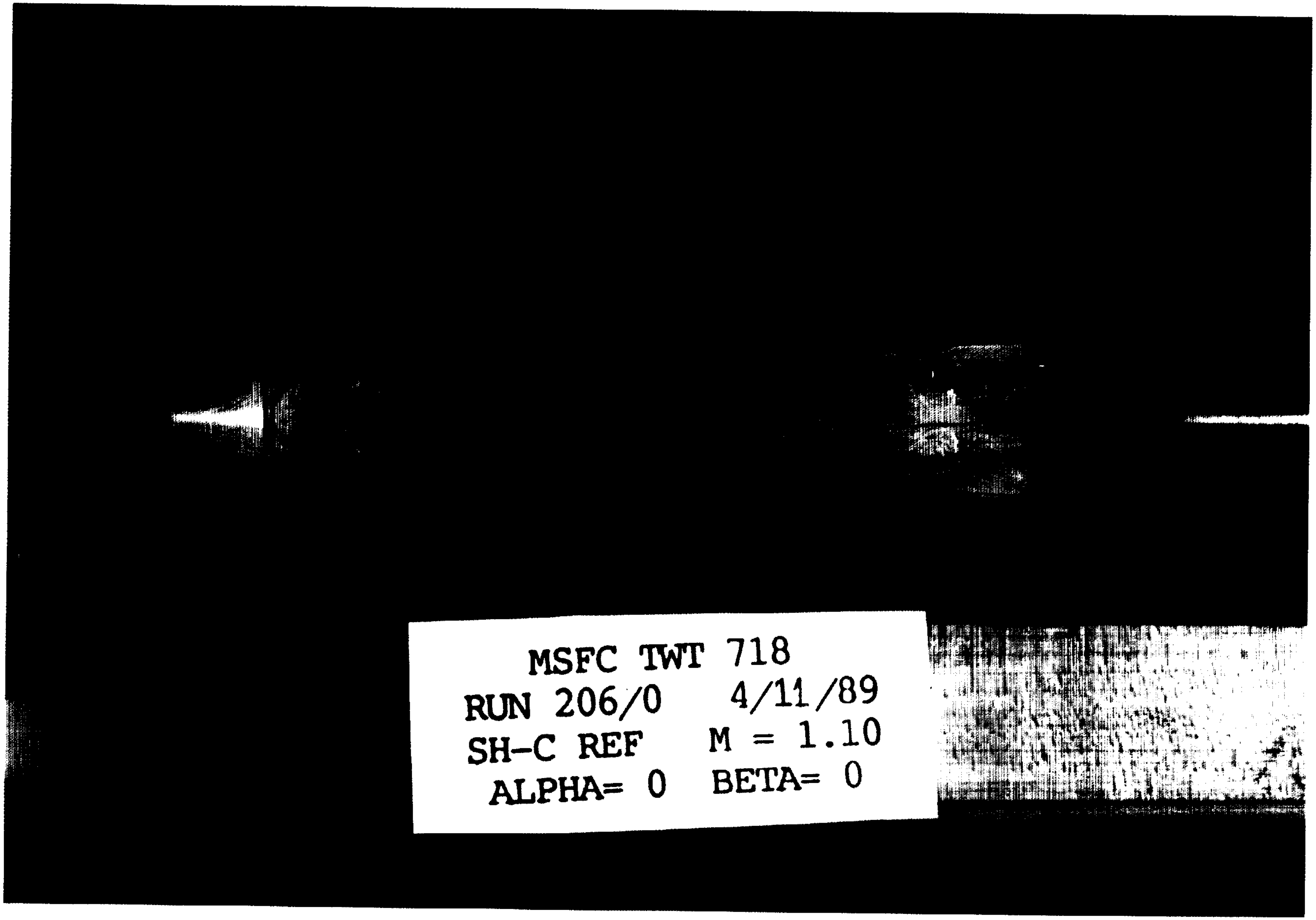



Figure 4. Shuttle-C cargo carrier Mach 1.1, alpha = 0, beta = 0, phi = 90.

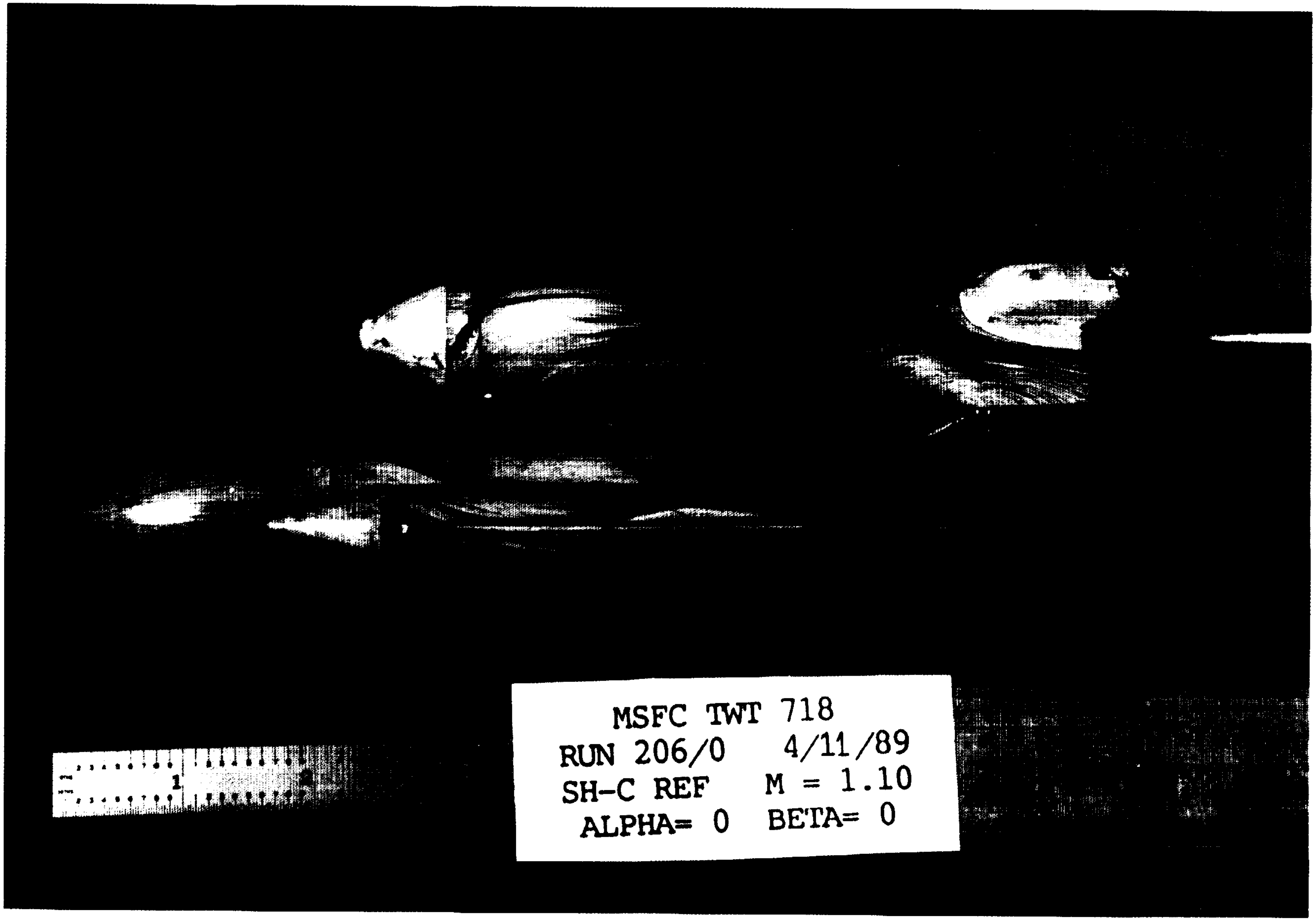



Figure 5. Shuttle-C mated vehicle Mach 1.1, alpha = 0, beta = 0, phi = 0.

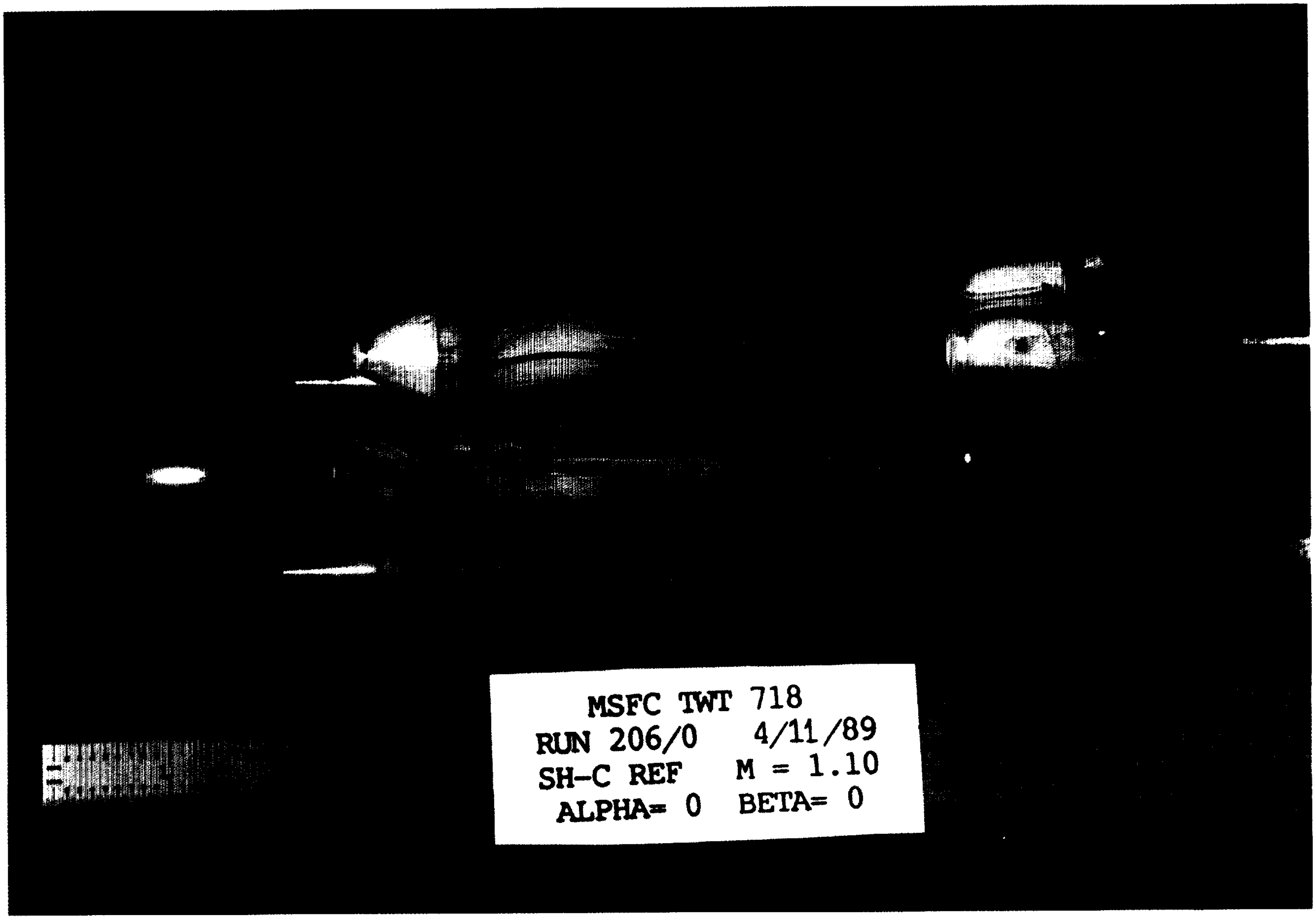



Figure 6. Shuttle-C mated vehicle Mach 1.1, alpha = 0, beta = 0, phi = 45.

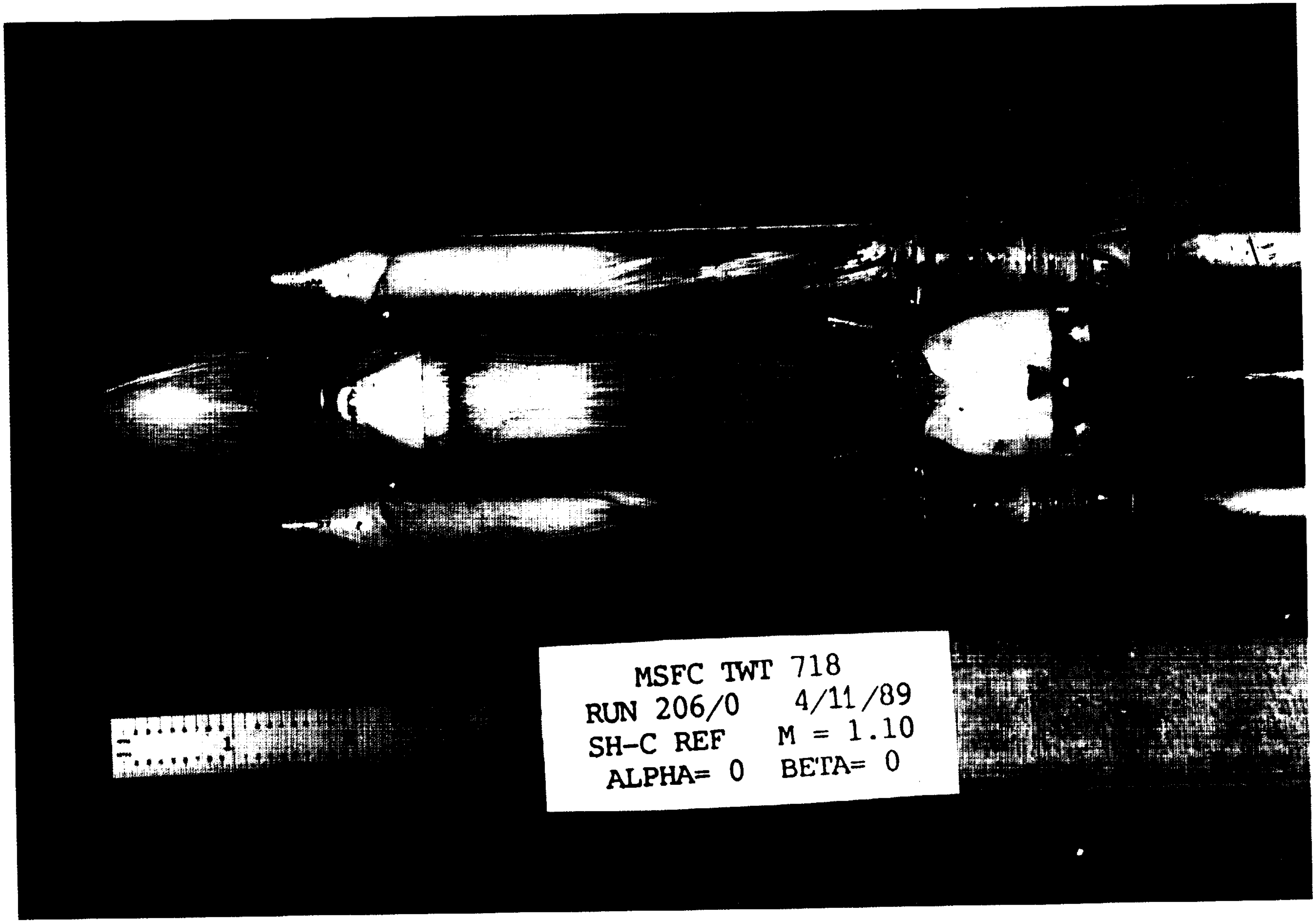



Figure 7. Shuttle-C mated vehicle Mach 1.1, alpha = 0, beta = 0, phi = 90.

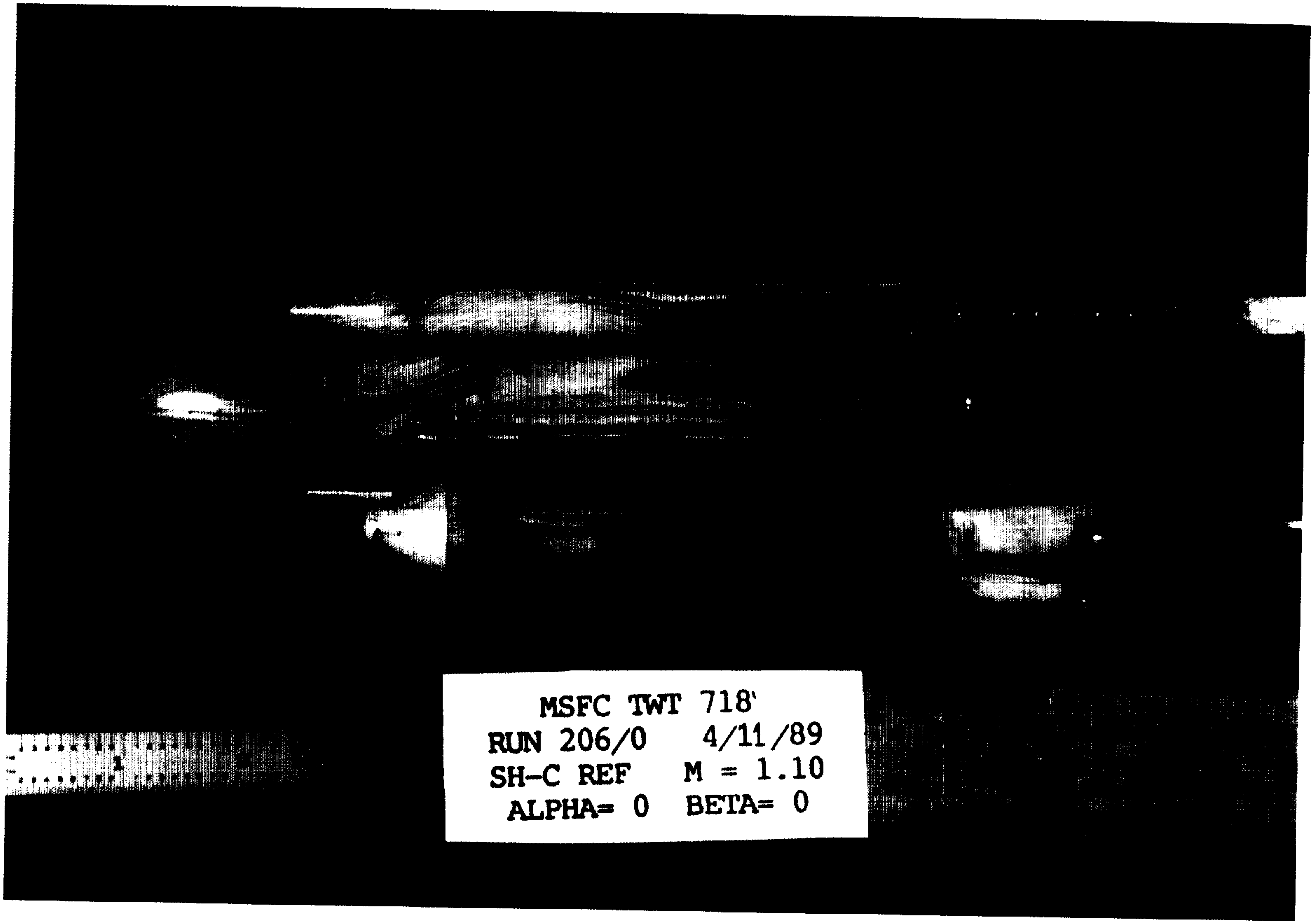



Figure 8. Shuttle-C mated vehicle Mach 1.1, alpha = 0, beta = 0, phi = 135.

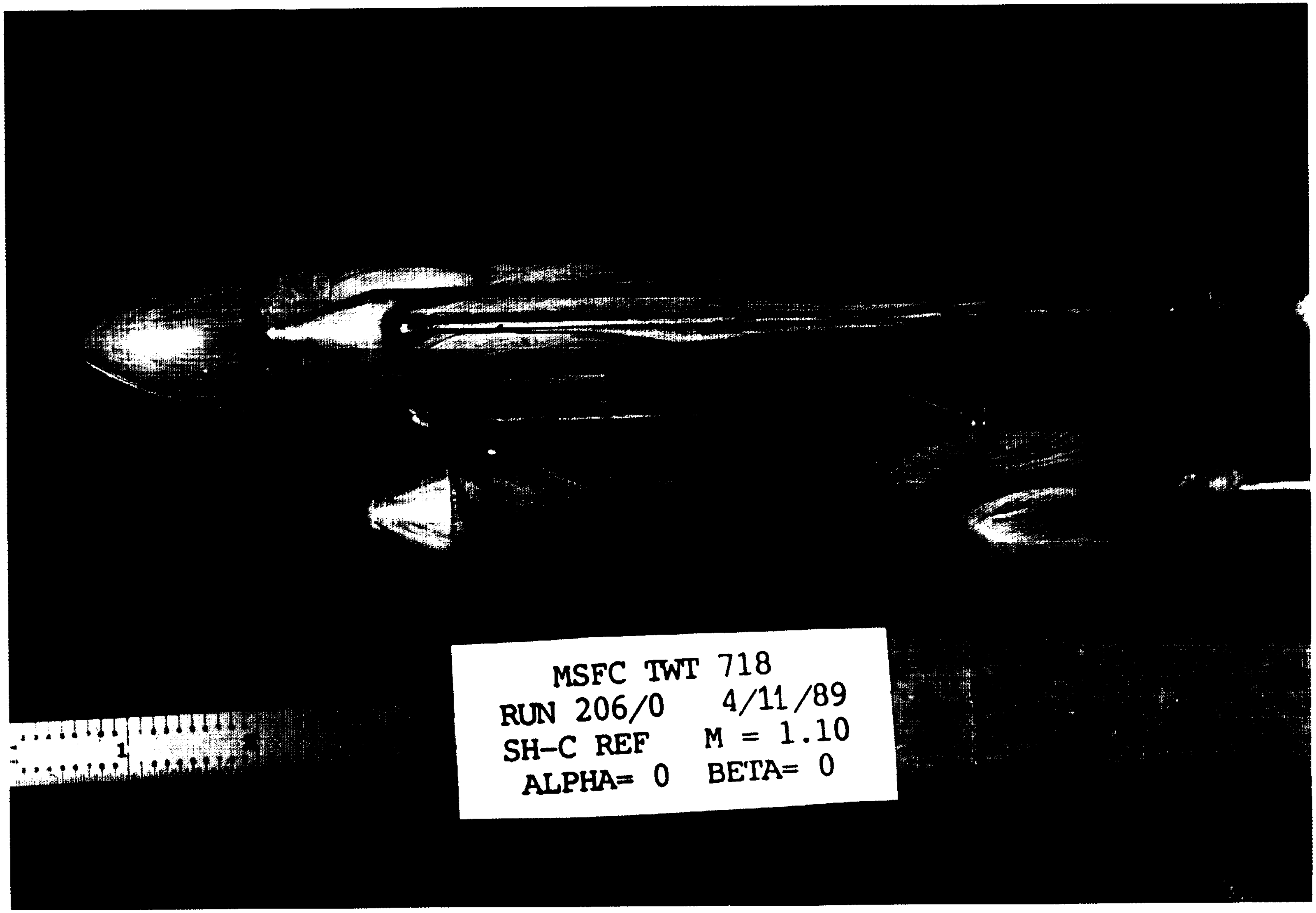



Figure 9. Shuttle-C mated vehicle Mach 1.1, alpha = 0, beta = 0, phi = 180.

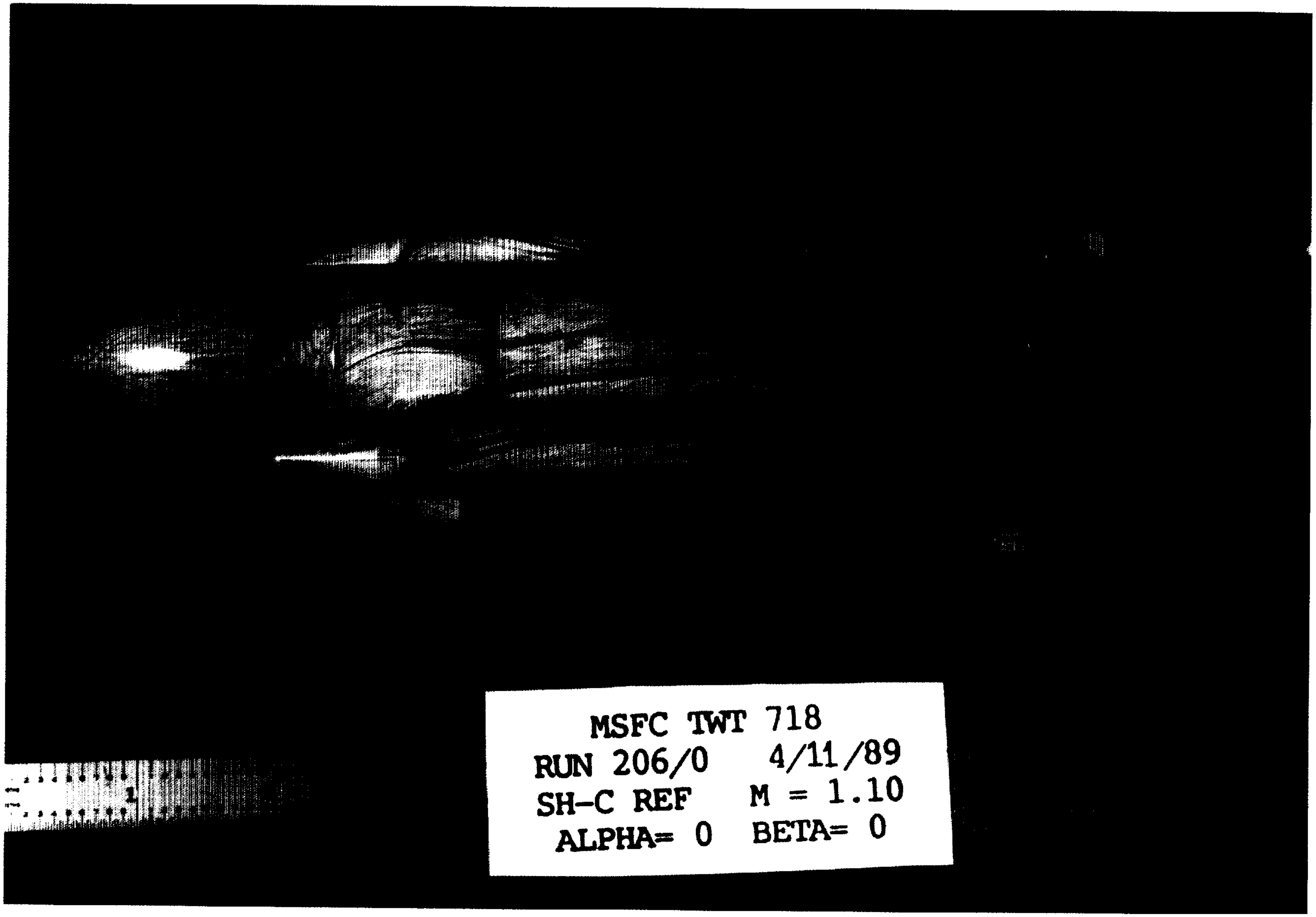



Figure 10. Shuttle-C mated vehicle Mach 1.1, alpha = 0, beta = 0, phi = 225.

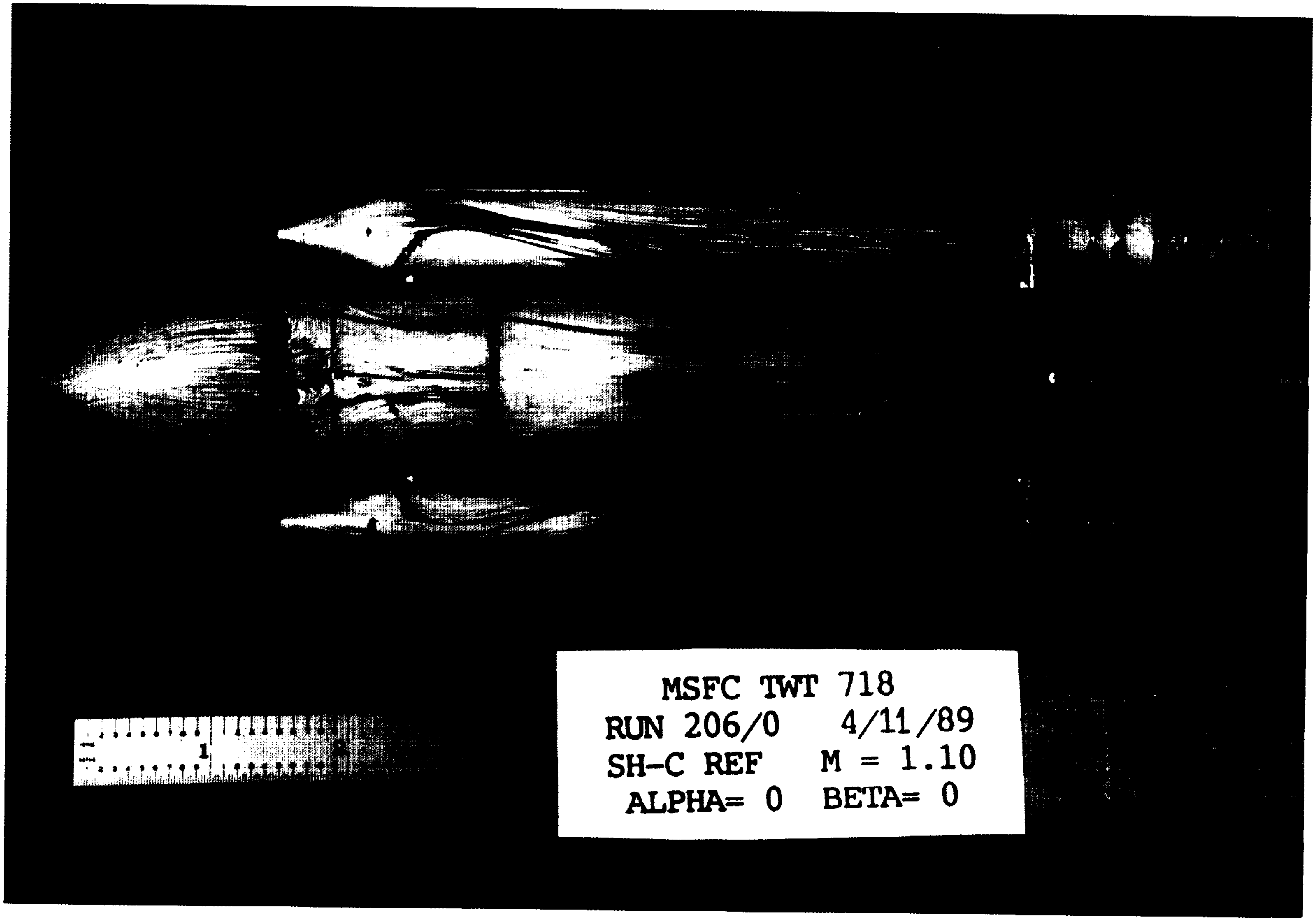



Figure 11. Shuttle-C mated vehicle Mach 1.1, alpha = 0, beta = 0, phi = 270.

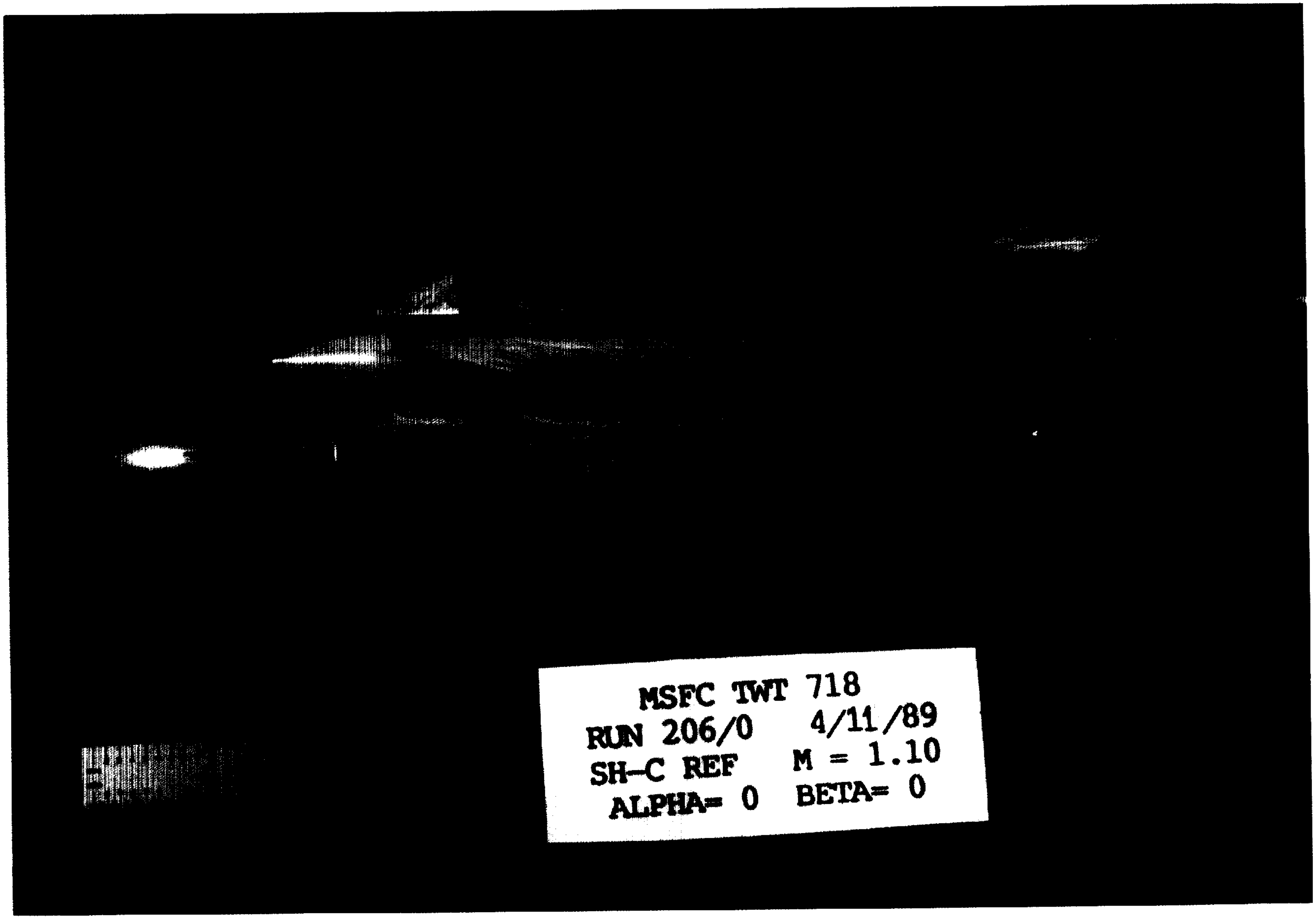



Figure 12. Shuttle-C mated vehicle Mach 1.1, alpha = 0, beta = 0, phi = 315.

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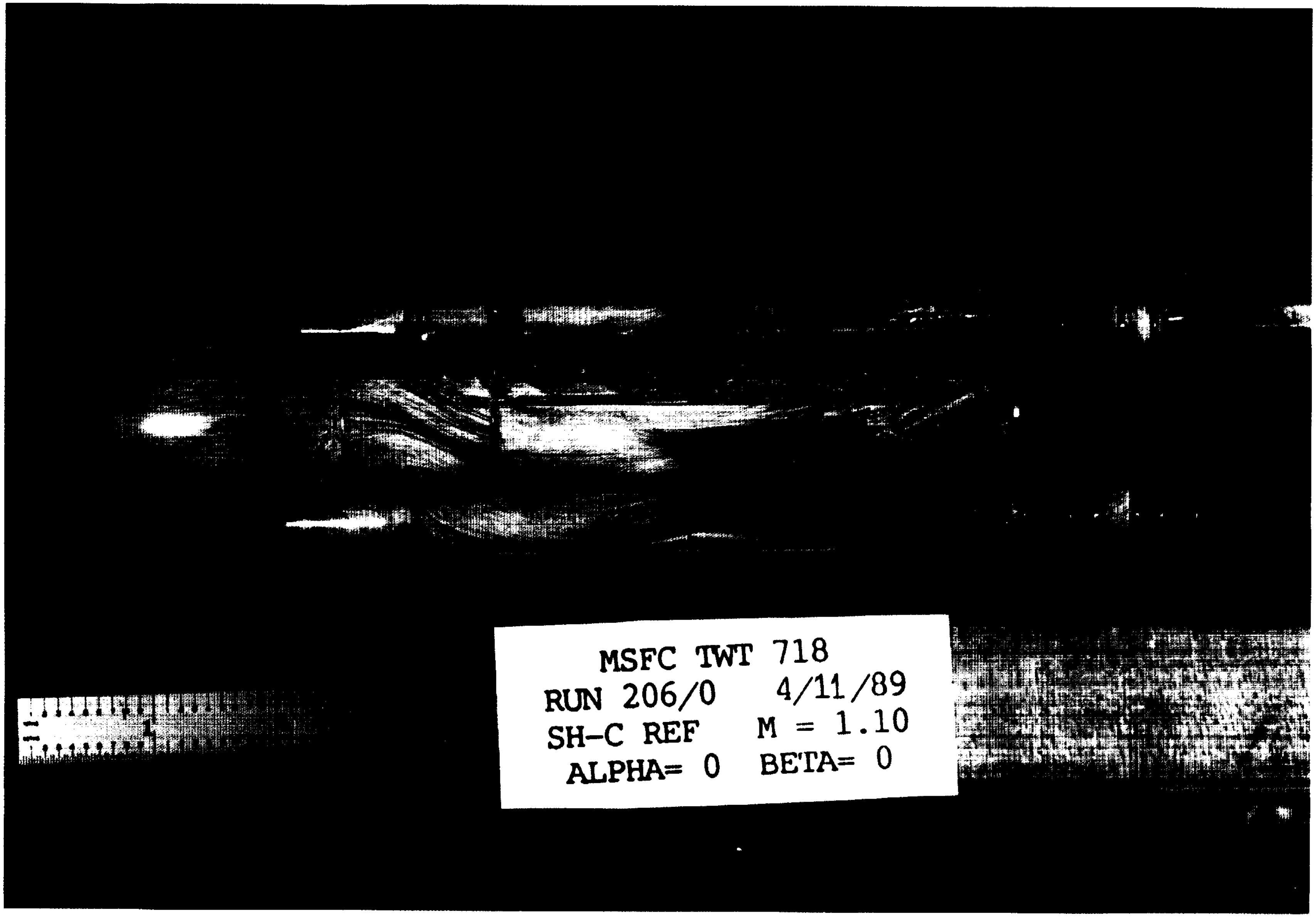


Figure 13. Shuttle-C lower stack Mach 1.1, alpha = 0, beta = 0, phi = 0.

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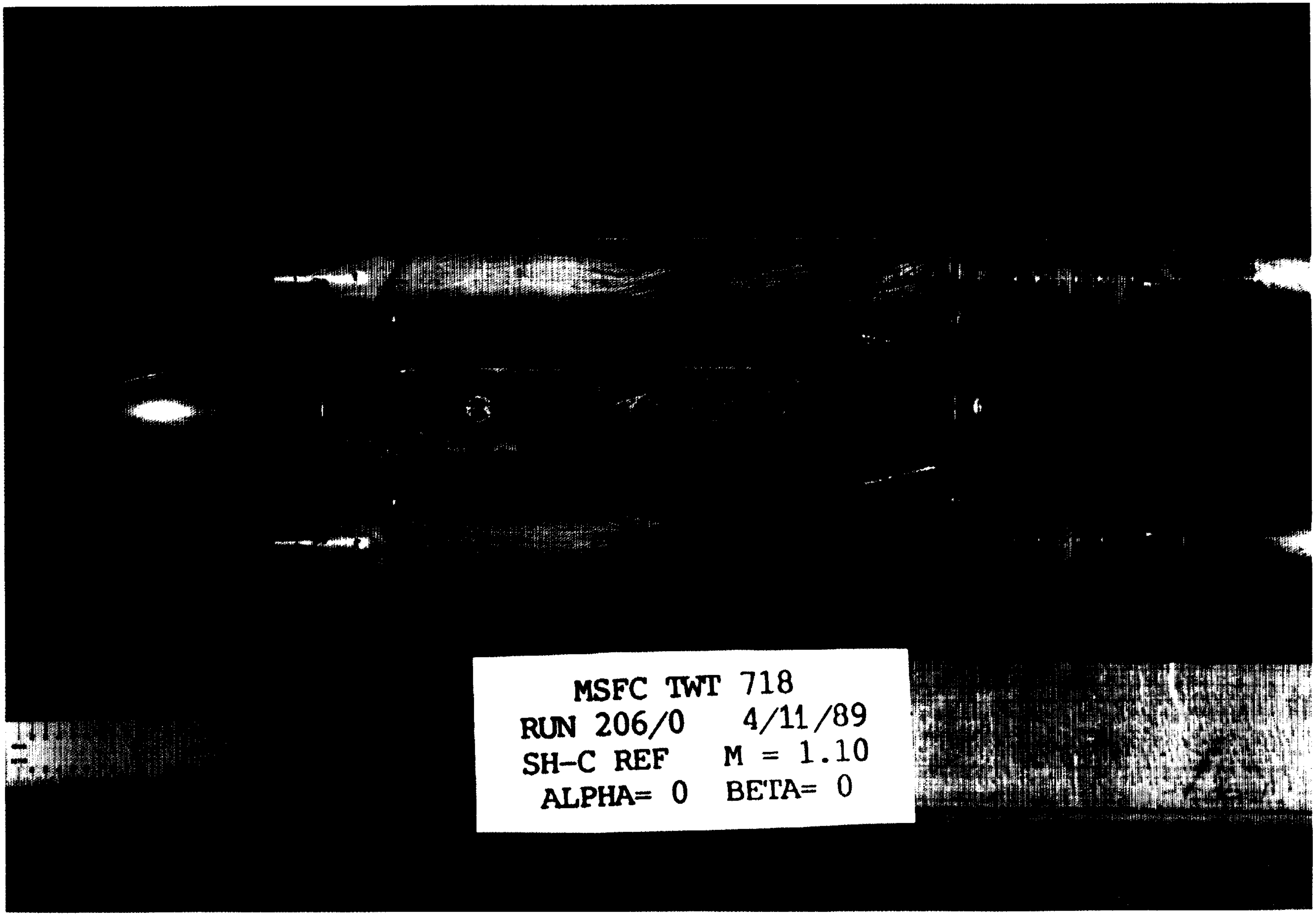


Figure 14. Shuttle-C lower stack Mach 1.1, alpha = 0, beta = 0, phi = 45.

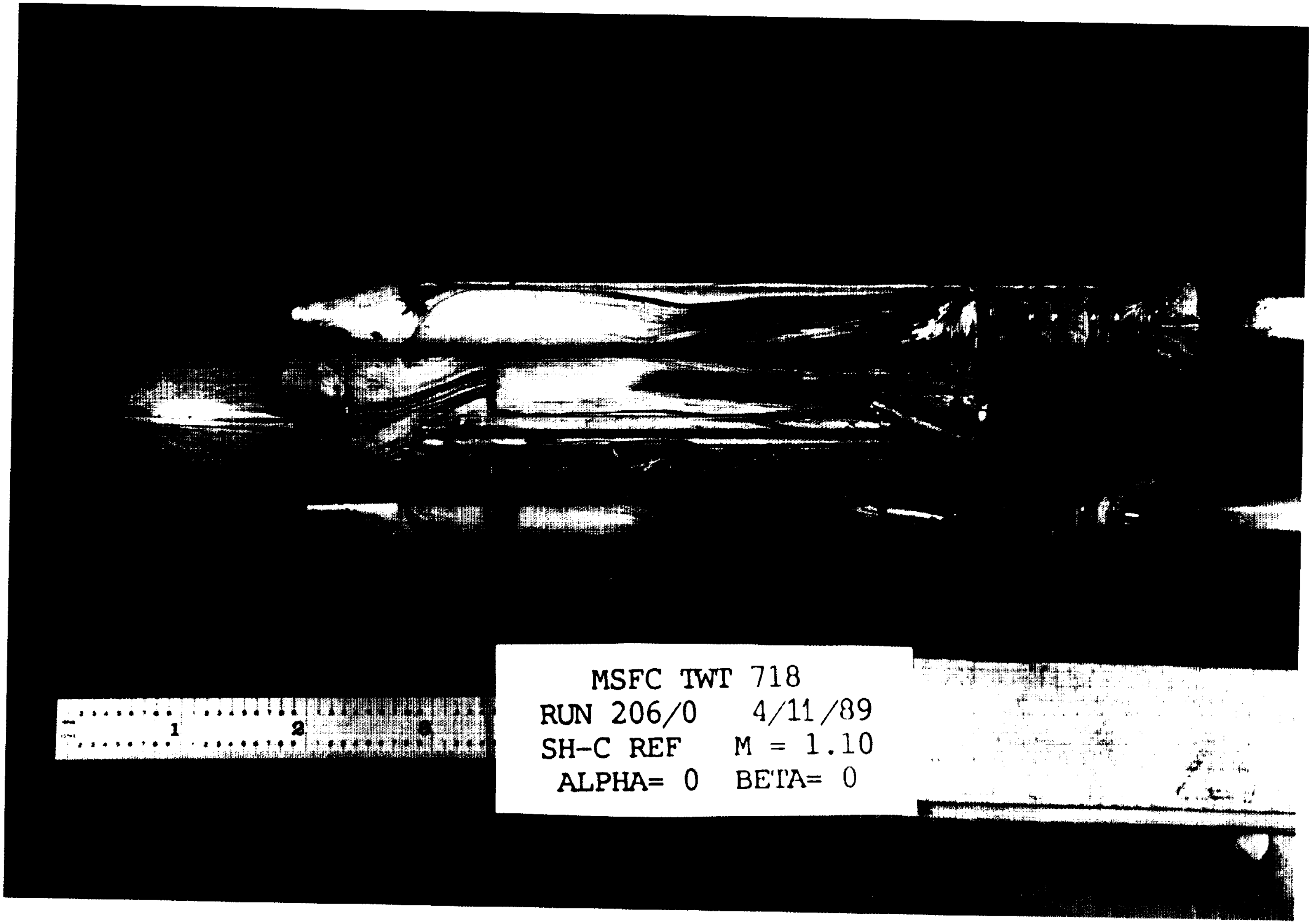


Figure 15. Shuttle-C lower stack Mach 1.1, alpha = 0, beta = 0, phi = 90.

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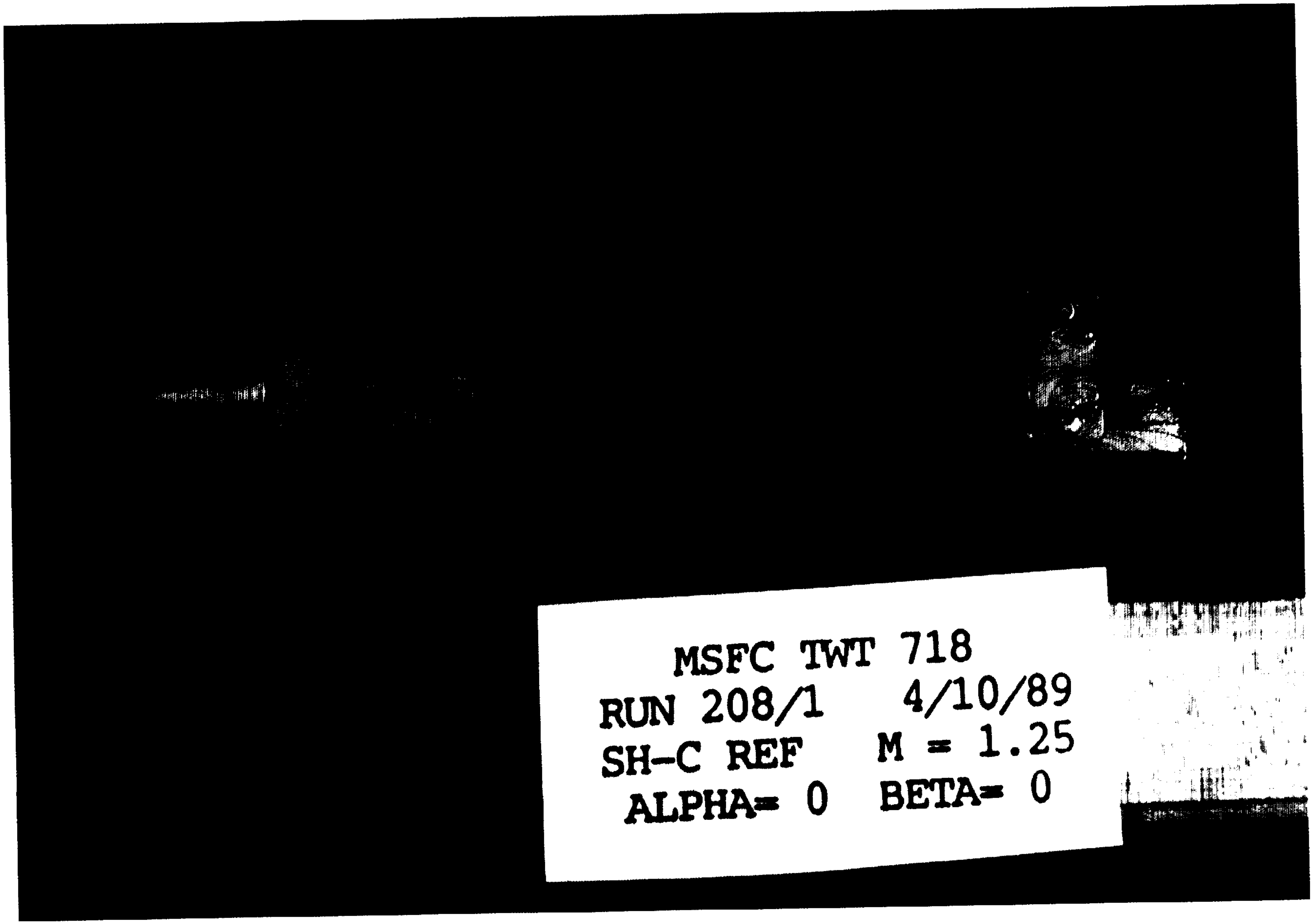


Figure 16. Shuttle-C cargo carrier Mach 1.25, alpha = 0, beta = 0, phi = 90.

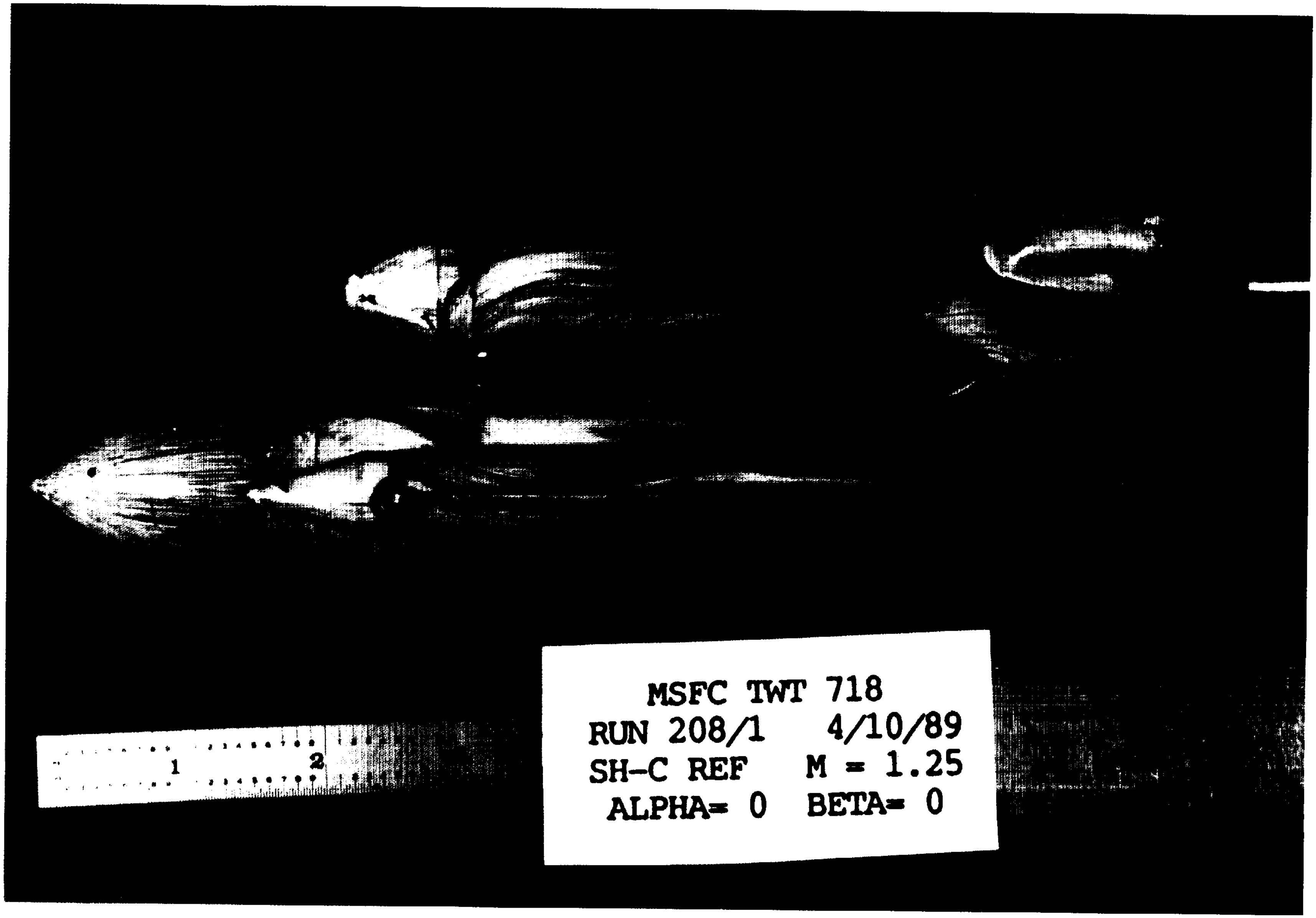


Figure 17. Shuttle-C mated vehicle Mach 1.25, alpha = 0, beta = 0, phi = 0.

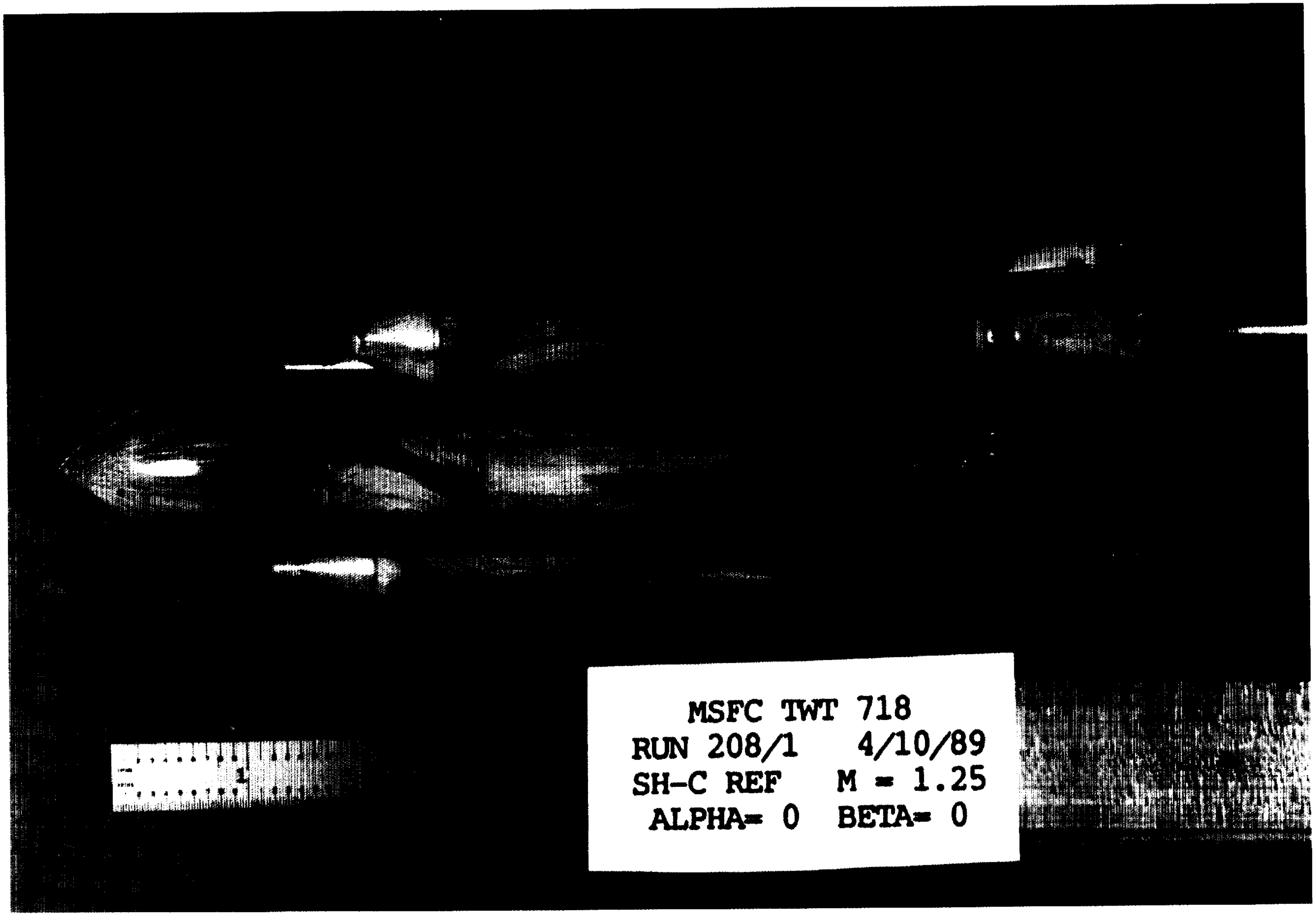


Figure 18. Shuttle-C mated vehicle Mach 1.25, alpha = 0, beta = 0, phi = 45.

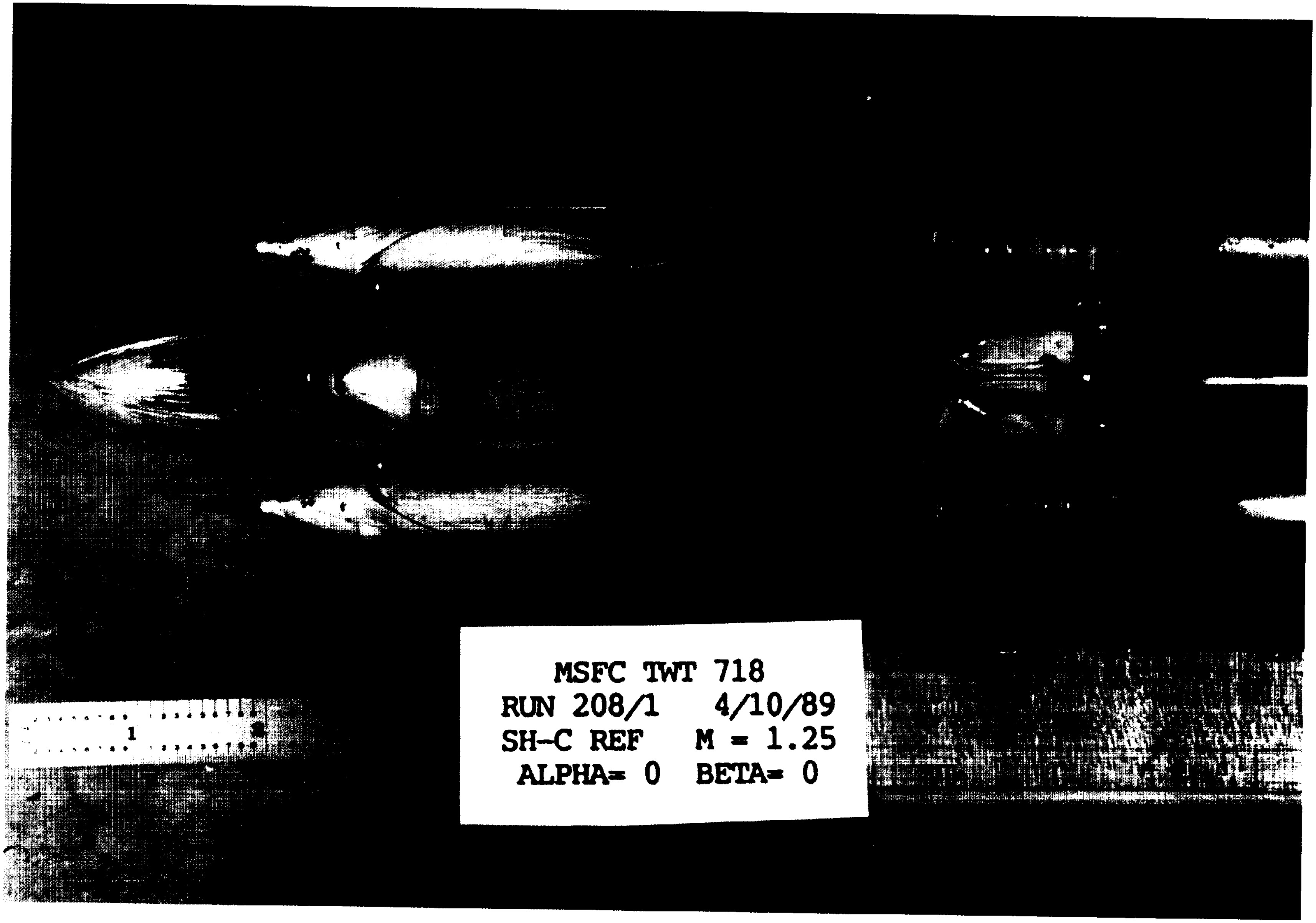


Figure 19. Shuttle-C mated vehicle Mach 1.25, alpha = 0, beta = 0, phi = 90.

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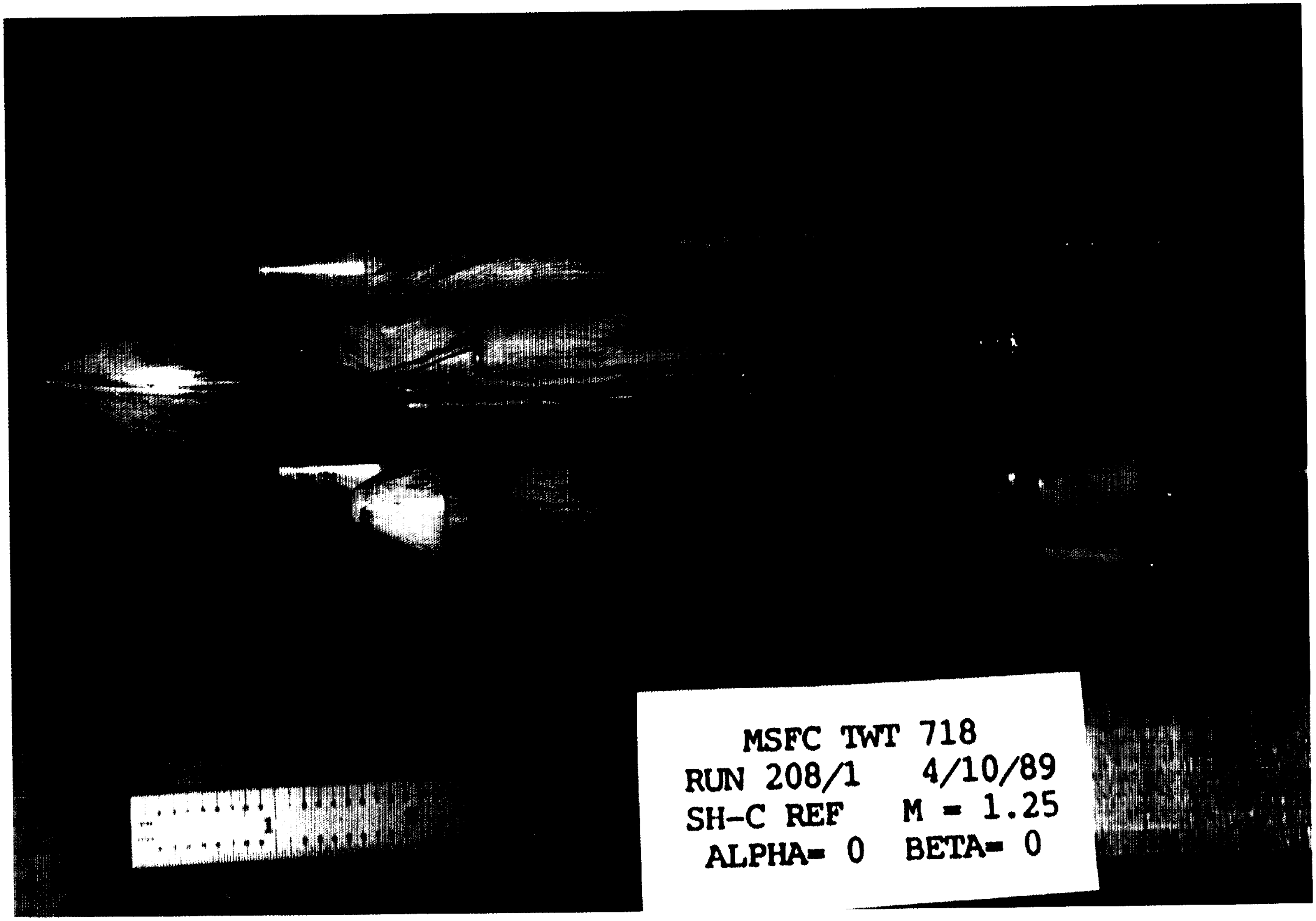


Figure 20. Shuttle-C mated vehicle Mach 1.25, alpha = 0, beta = 0, phi = 135.

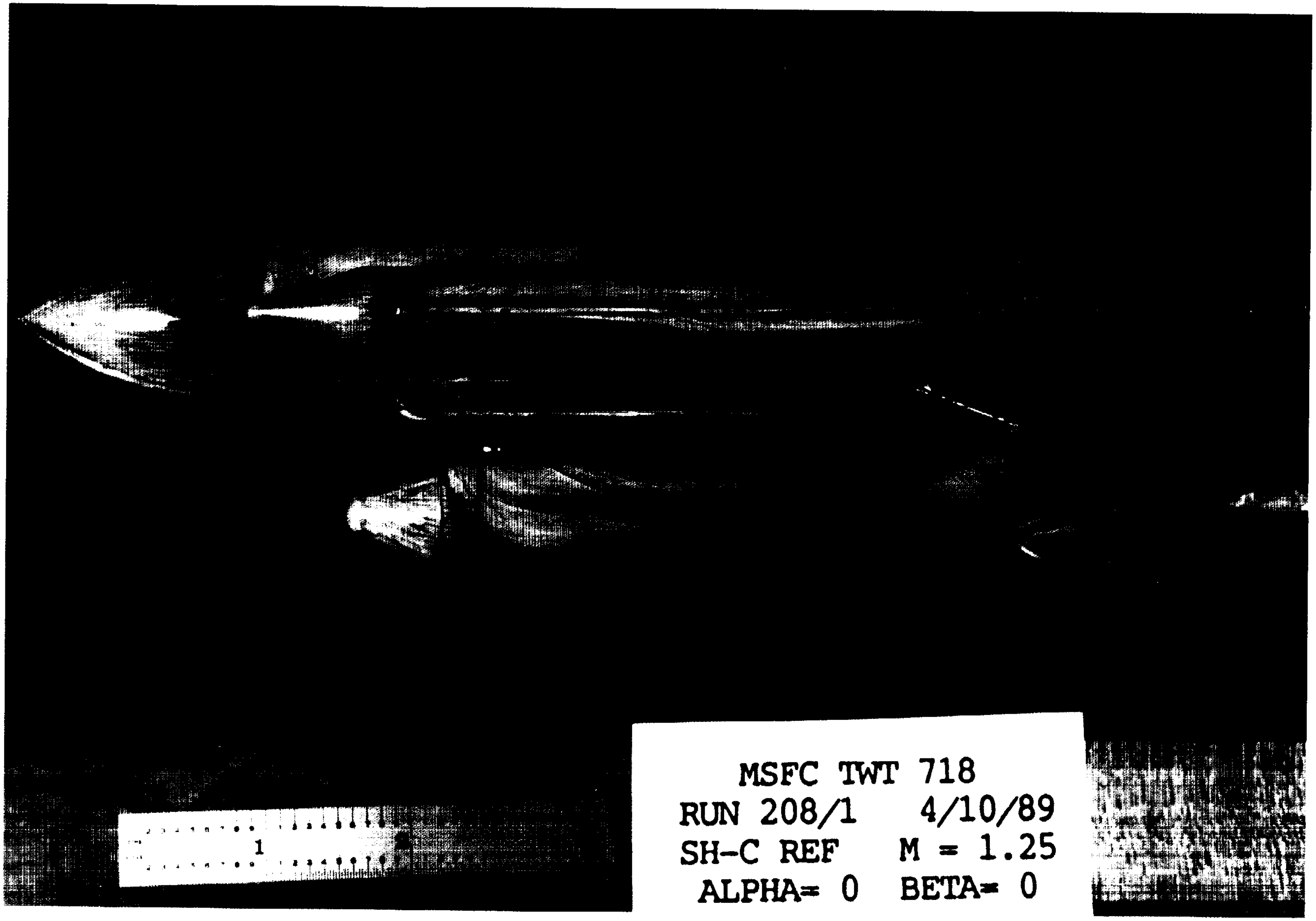


Figure 21. Shuttle-C mated vehicle Mach 1.25, alpha = 0, beta = 0, phi = 180.

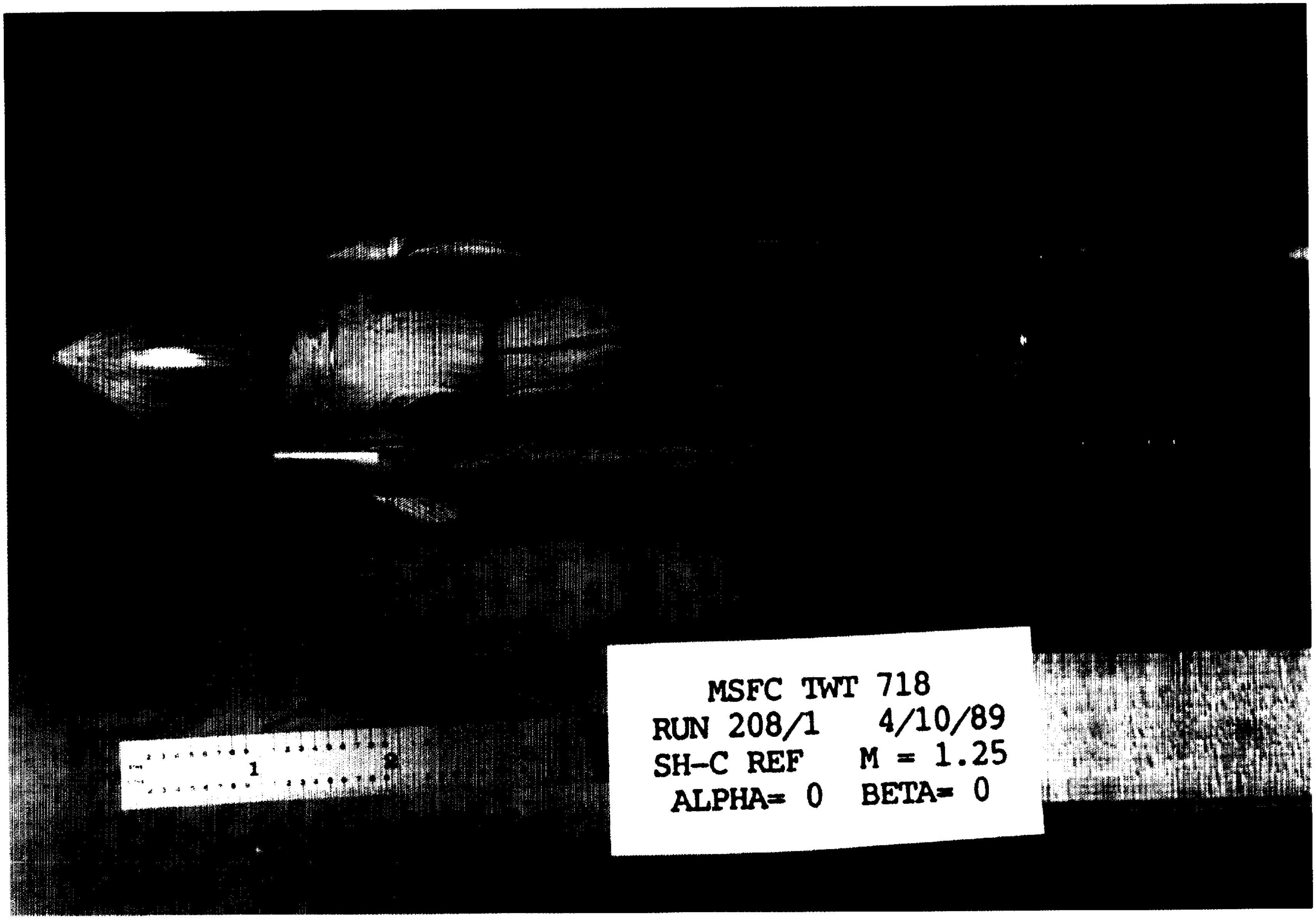


Figure 22. Shuttle-C mated vehicle Mach 1.25, alpha = 0, beta = 0, phi = 225.

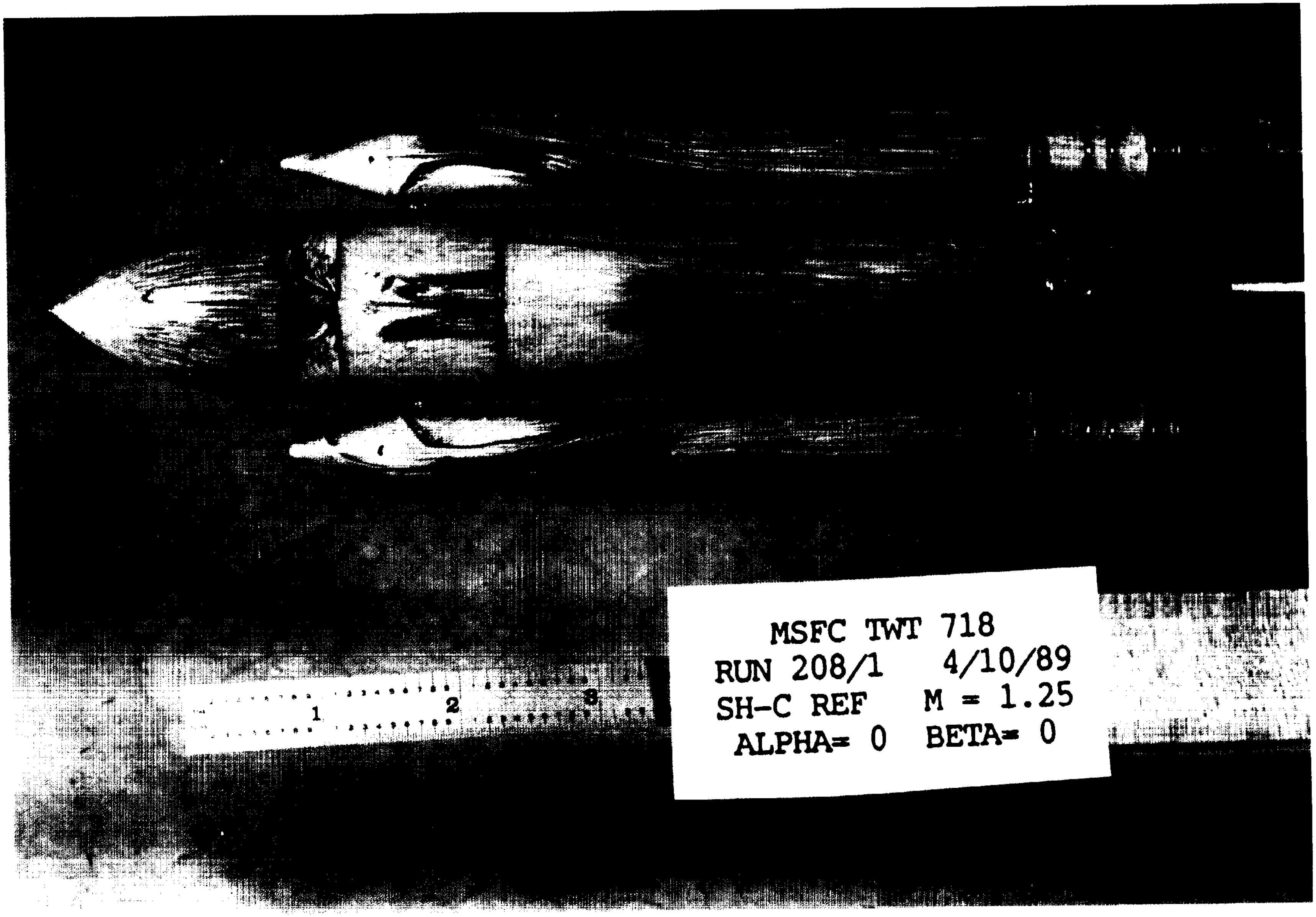


Figure 23. Shuttle-C mated vehicle Mach 1.25, alpha = 0, beta = 0, phi = 270.

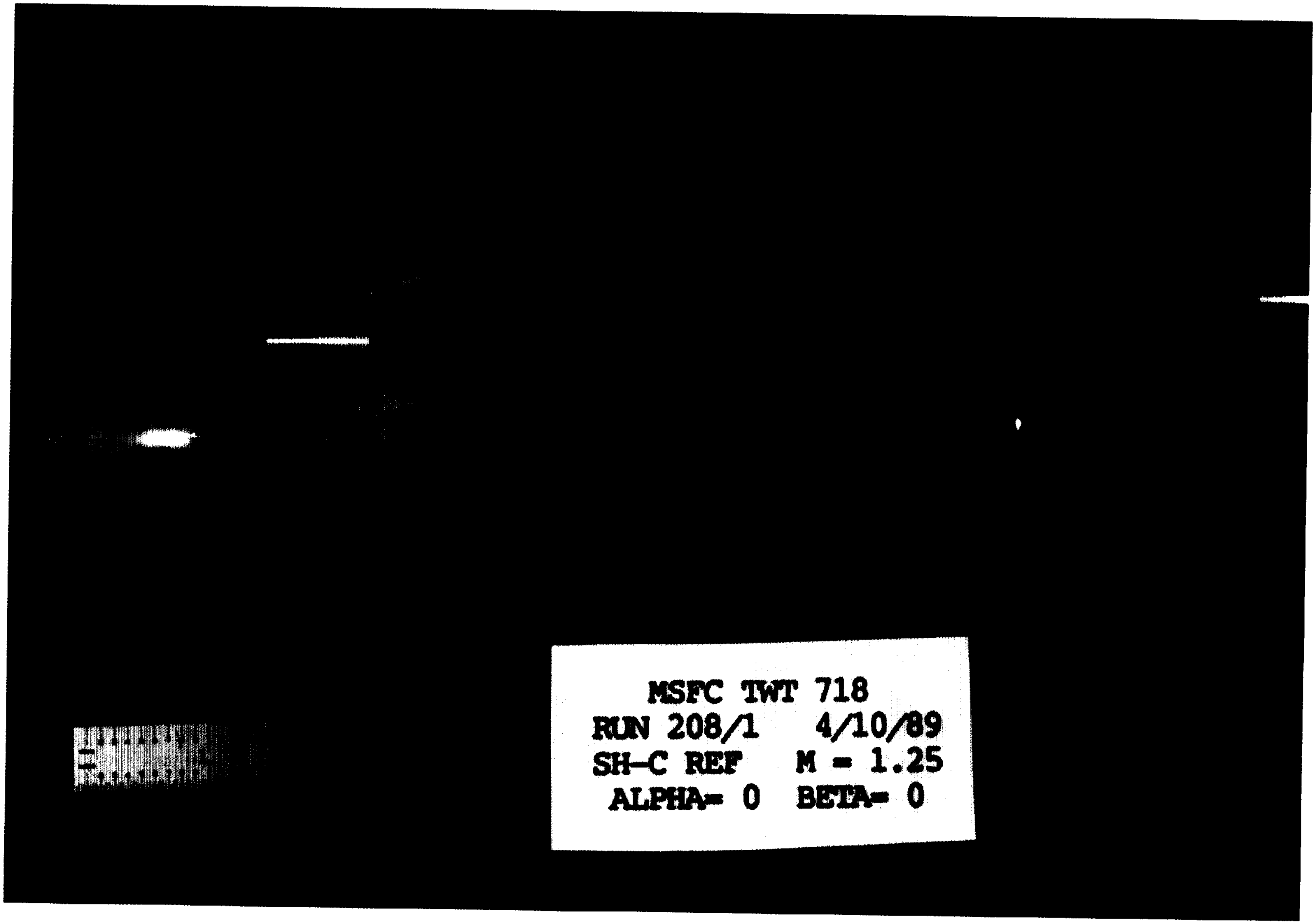


Figure 24. Shuttle-C mated vehicle Mach 1.25, alpha = 0, beta = 0, phi = 315.

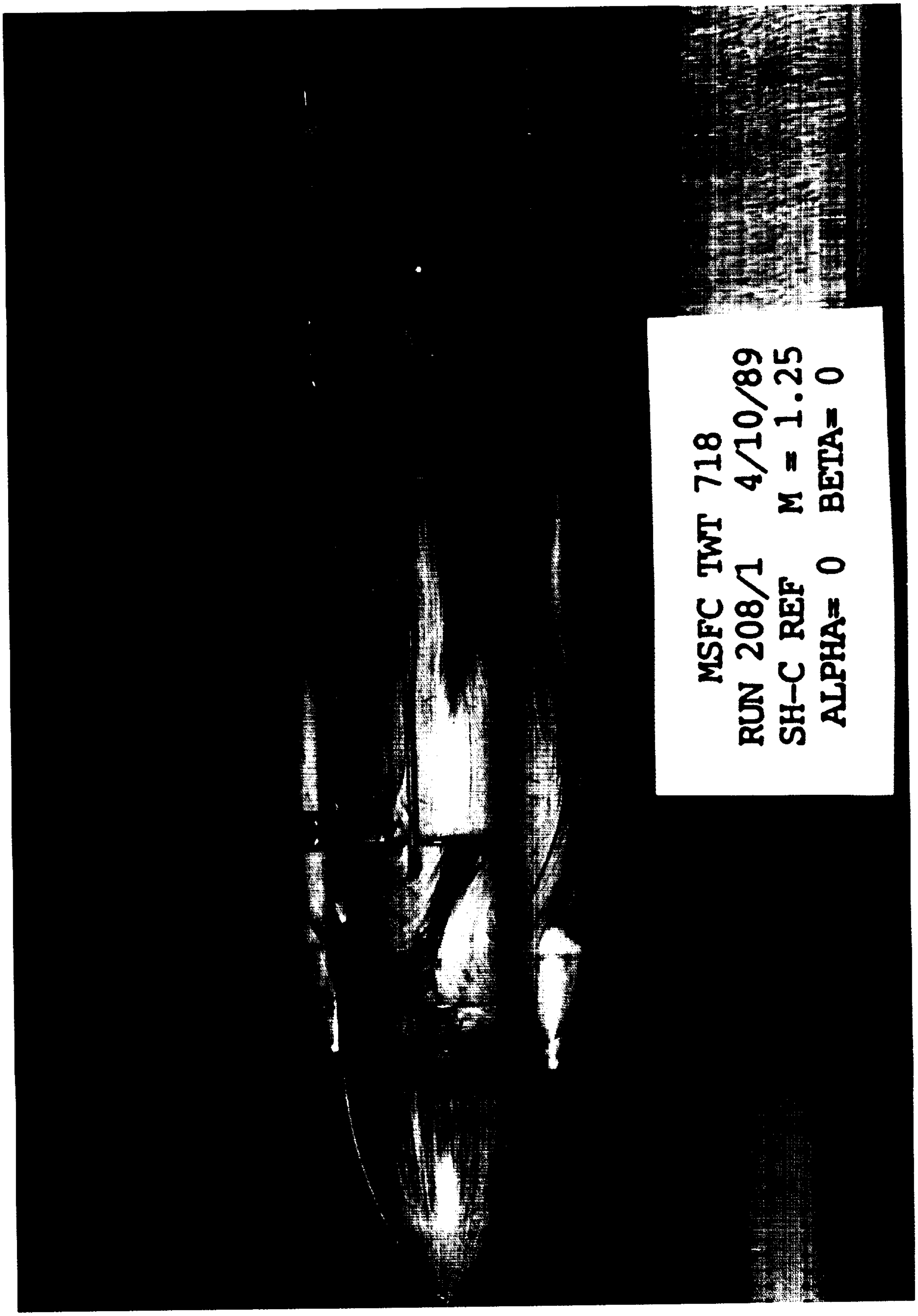


Figure 25. Shuttle-C lower stack Mach 1.25, alpha = 0, beta = 0, phi = 0.

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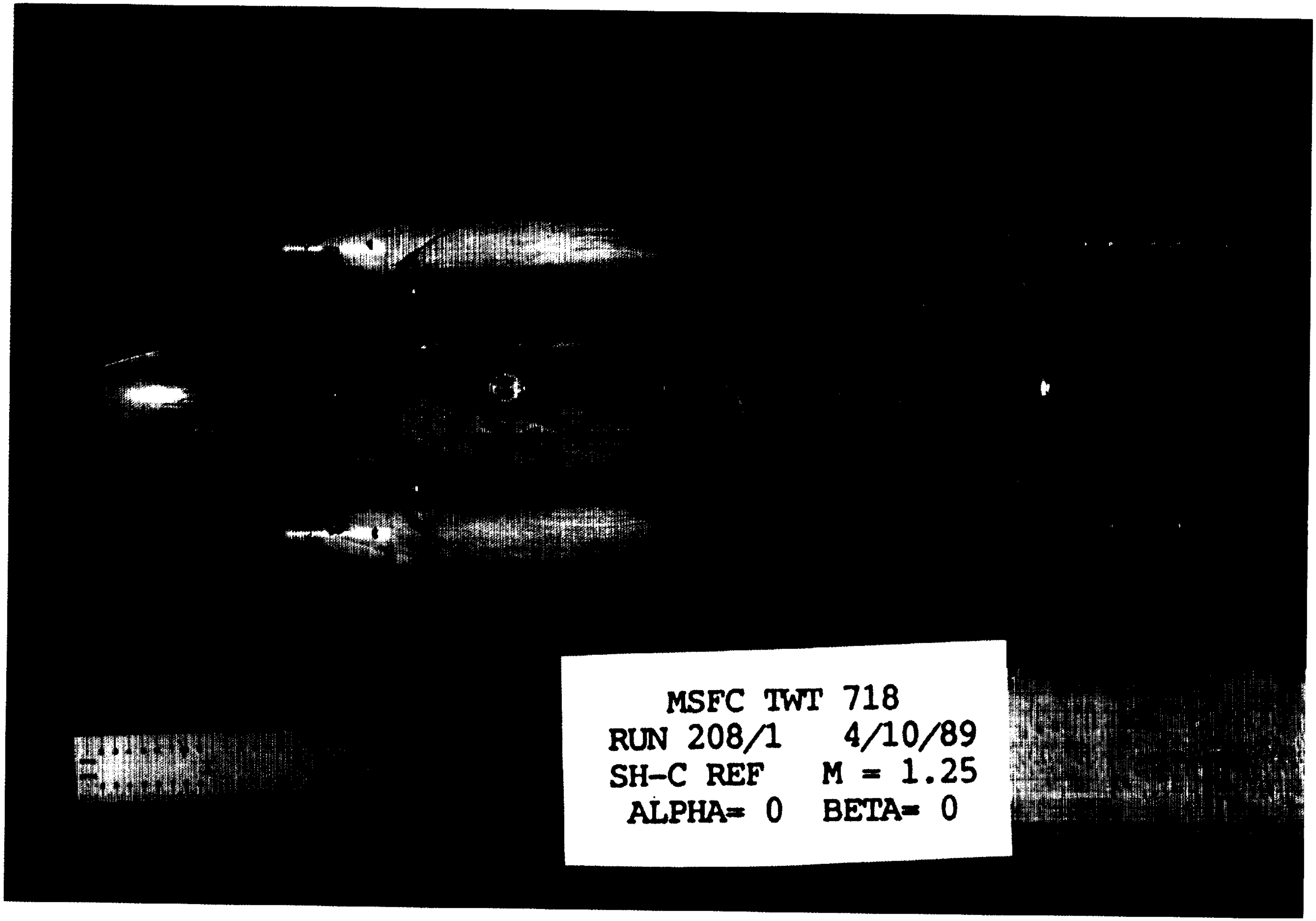


Figure 26. Shuttle-C lower stack Mach 1.25, alpha = 0, beta = 0, phi = 45.

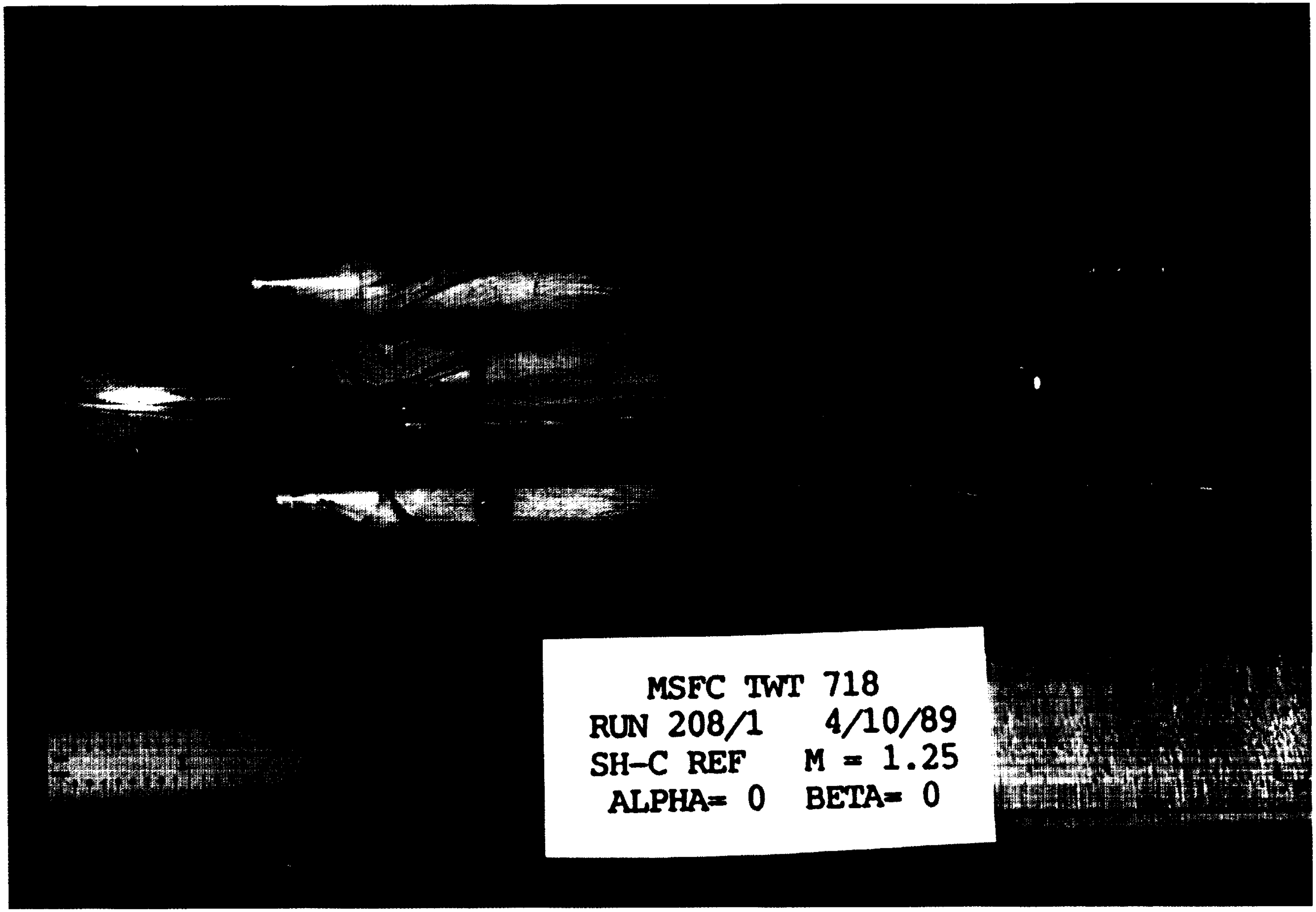


Figure 27. Shuttle-C lower stack Mach 1.25, alpha = 0, beta = 0, phi = 90.

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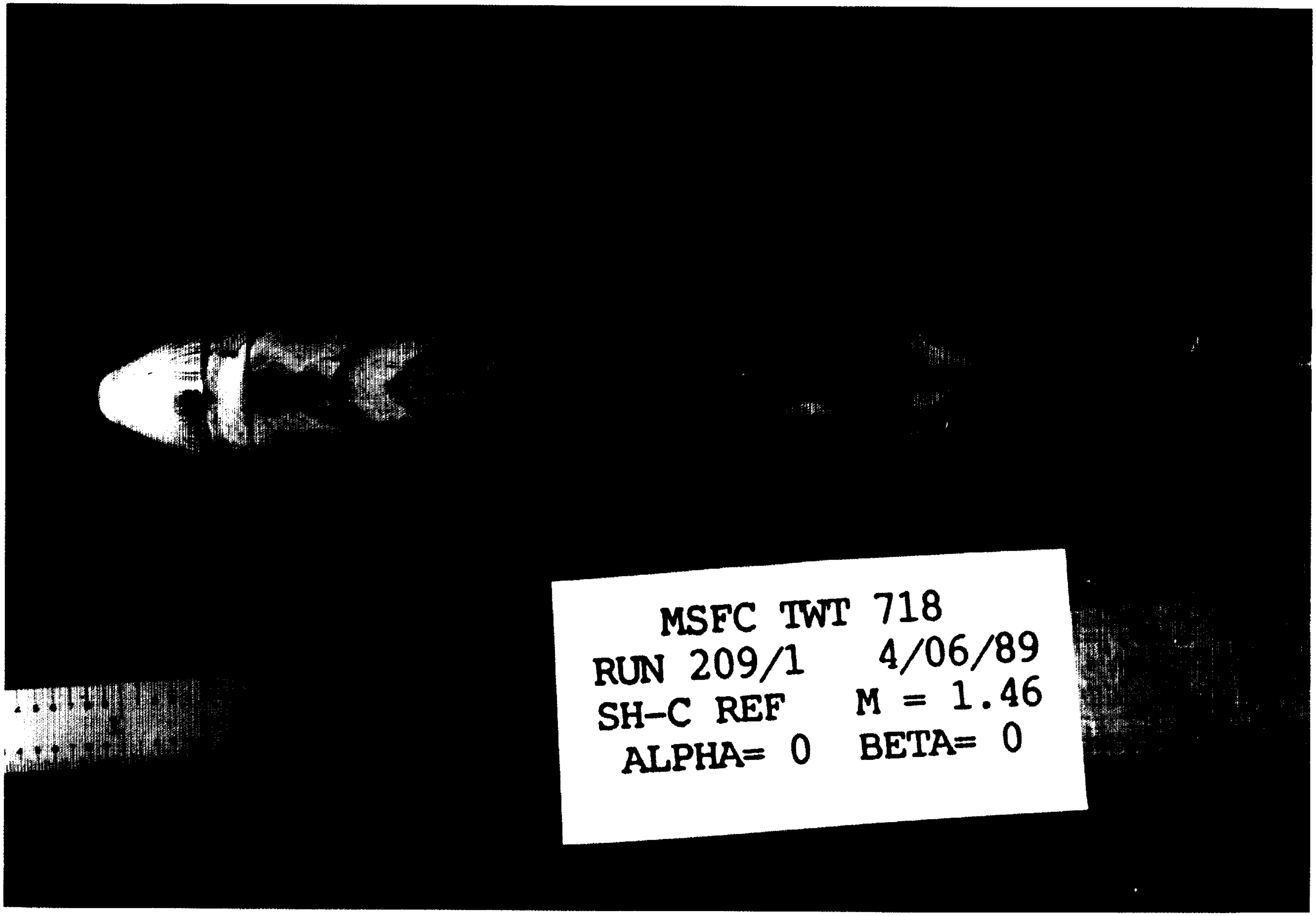


Figure 28. Shuttle-C cargo carrier Mach 1.46, alpha = 0, beta = 0, phi = 90.


Figure 29. Shuttle-C mated vehicle Mach 1.46, alpha = 0, beta = 0, phi = 0.

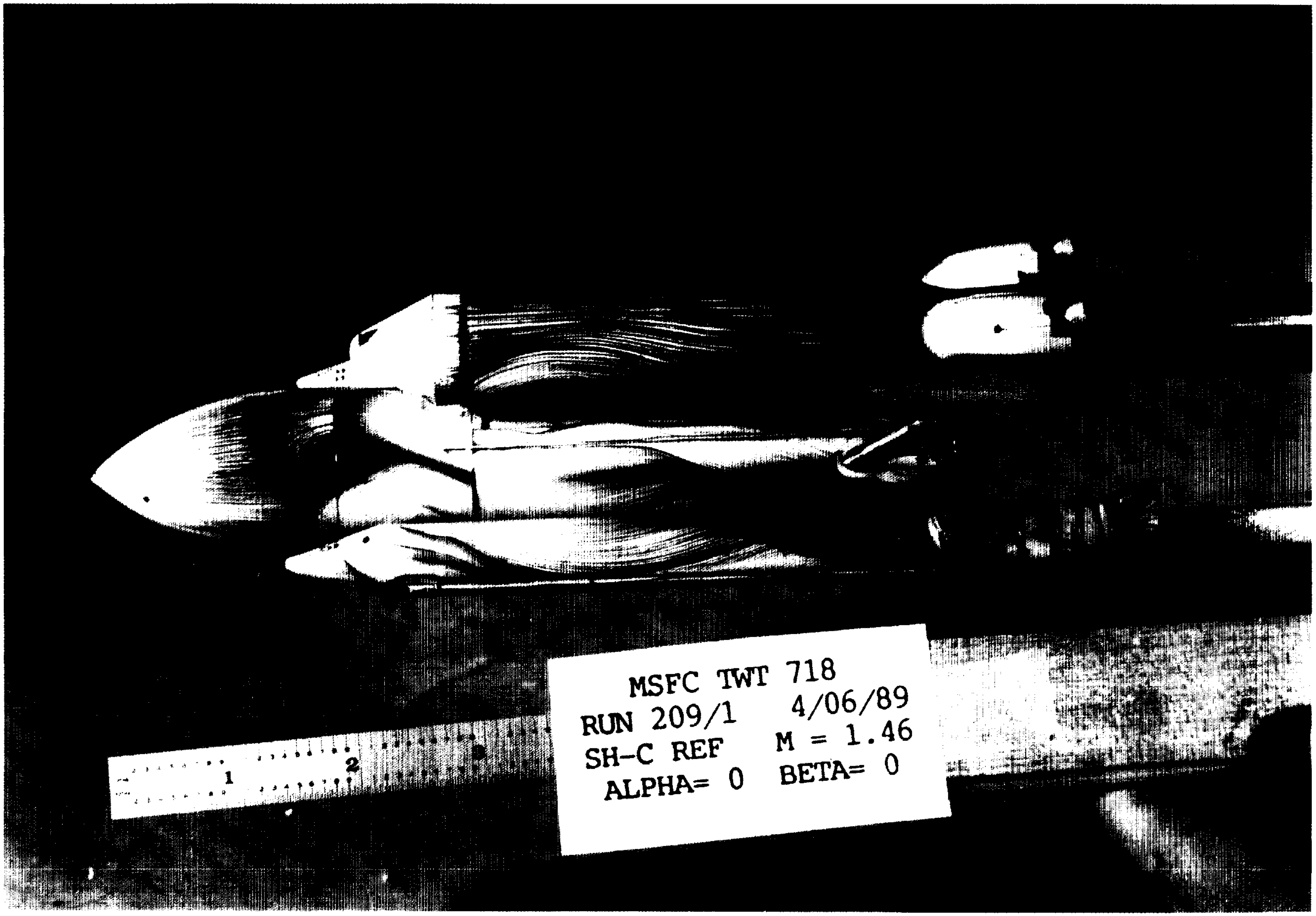


Figure 30. Shuttle-C mated vehicle Mach 1.46, alpha = 0, beta = 0, phi = 45.

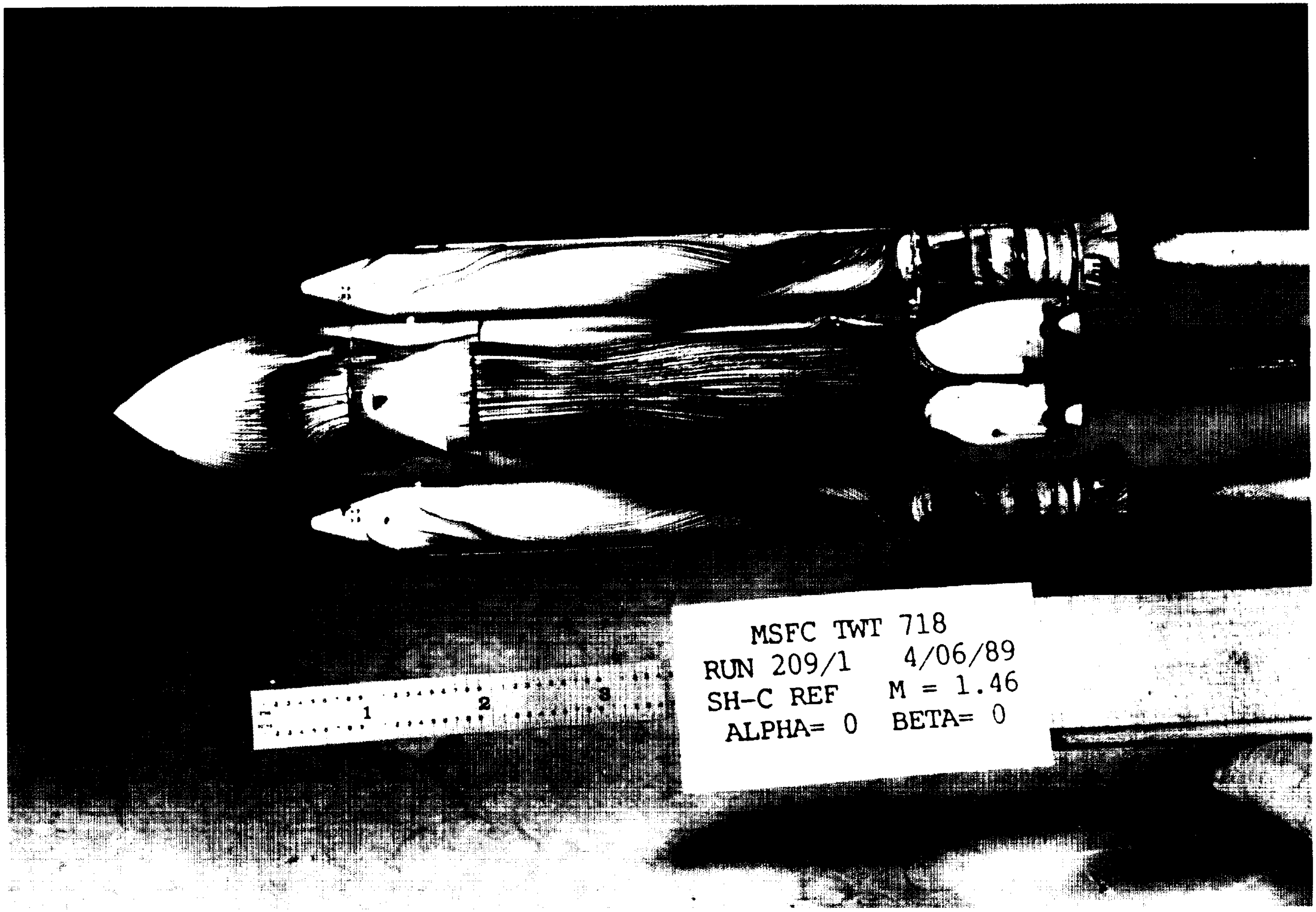


Figure 31. Shuttle-C mated vehicle Mach 1.46, alpha = 0, beta = 0, phi = 90.

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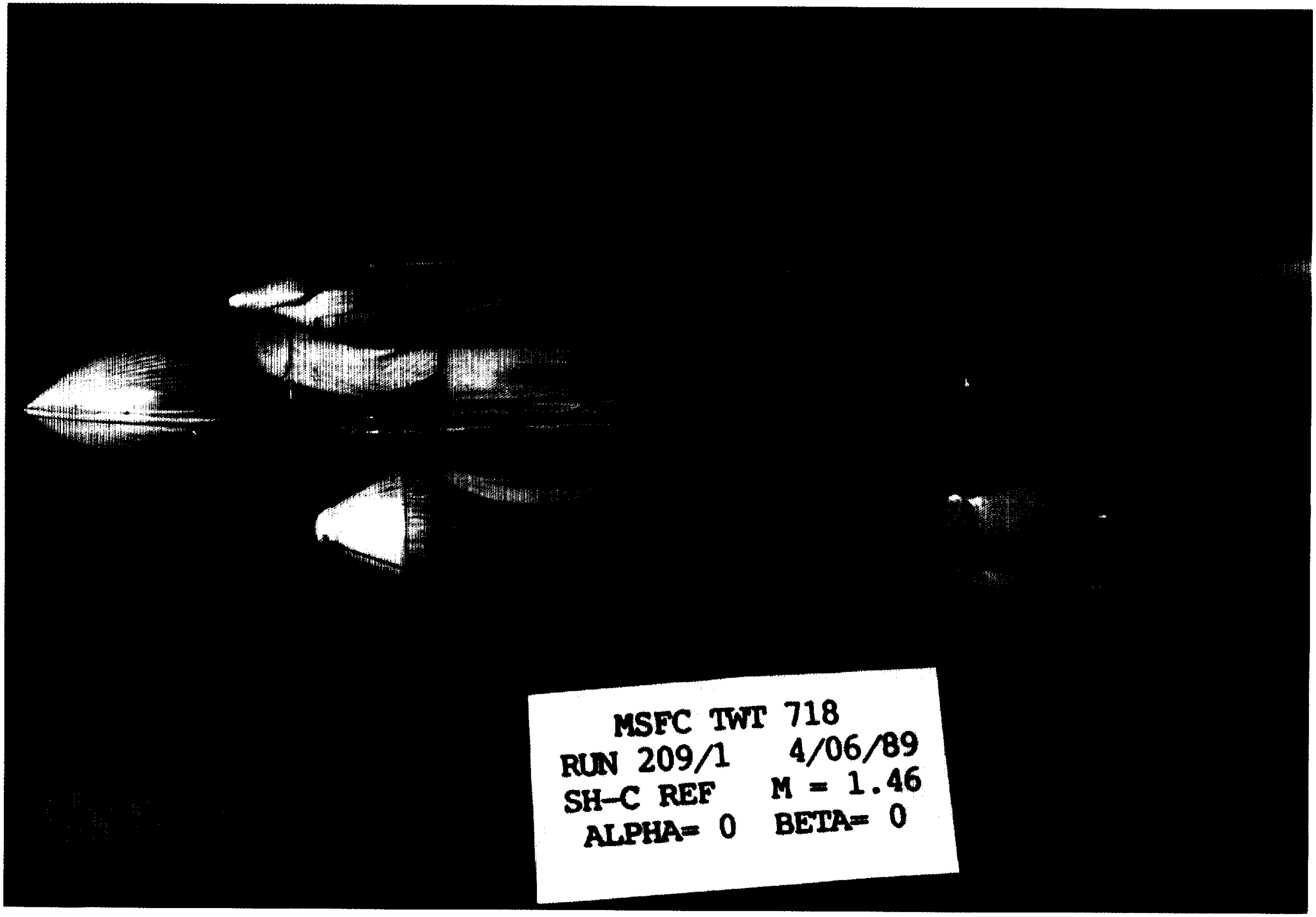


Figure 32. Shuttle-C mated vehicle Mach 1.46, alpha = 0, beta = 0, phi = 135.

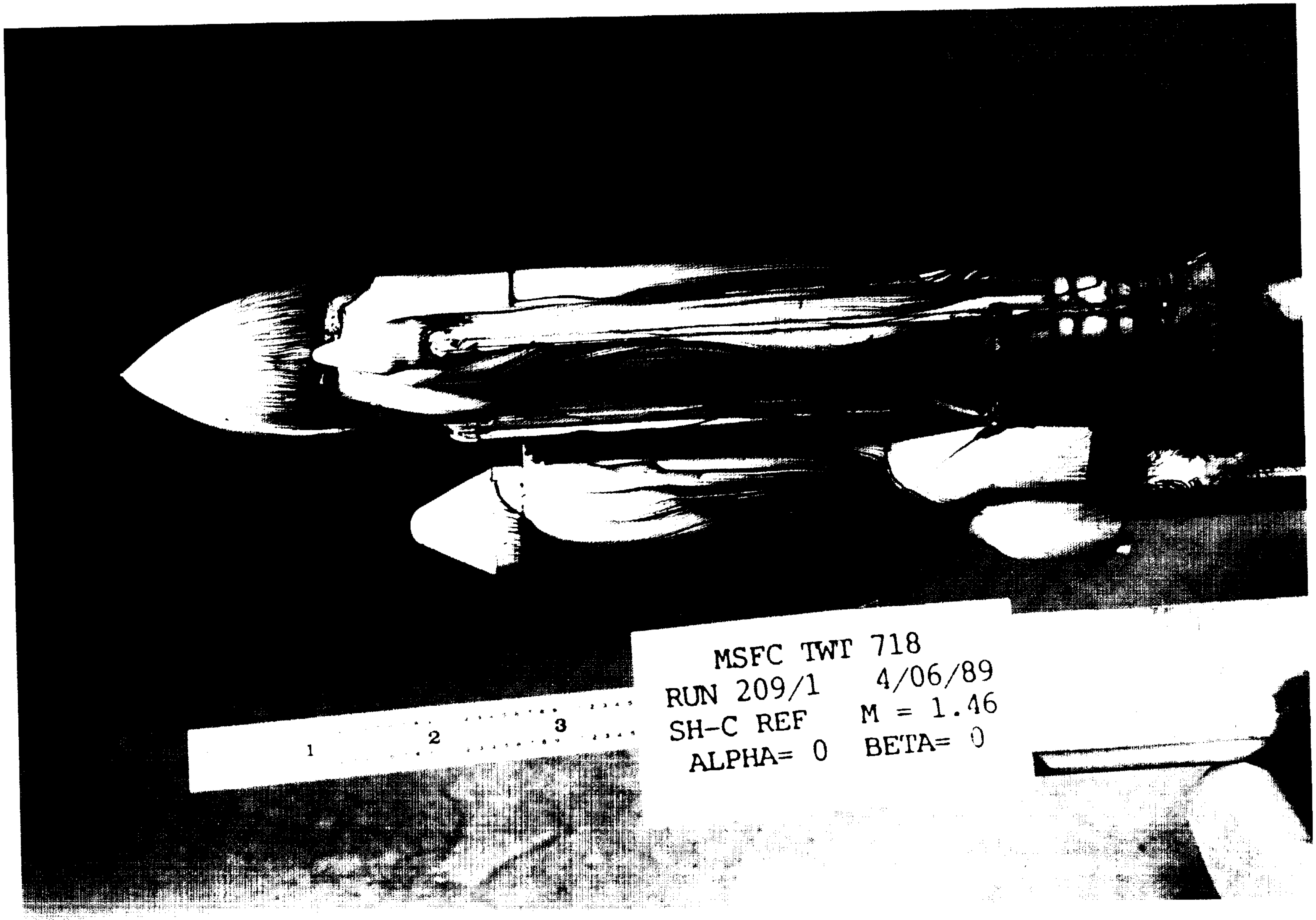


Figure 33. Shuttle-C mated vehicle Mach 1.46, alpha = 0, beta = 0, phi = 180.

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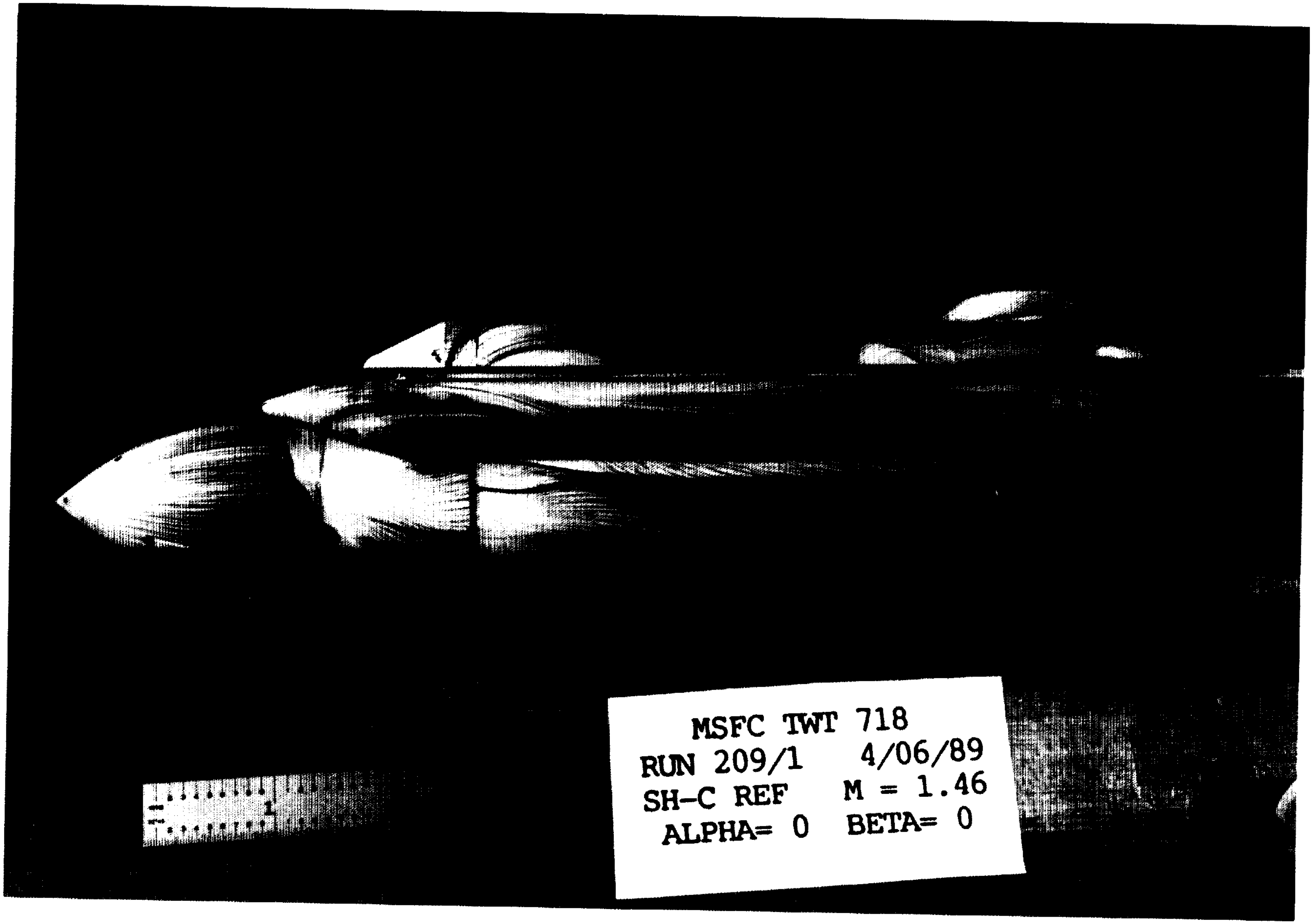


Figure 36. Shuttle-C mated vehicle Mach 1.46, alpha = 0, beta = 0, phi = 315.


Figure 37. Shuttle-C lower stack Mach 1.46, alpha = 0, beta = 0, phi = 0.

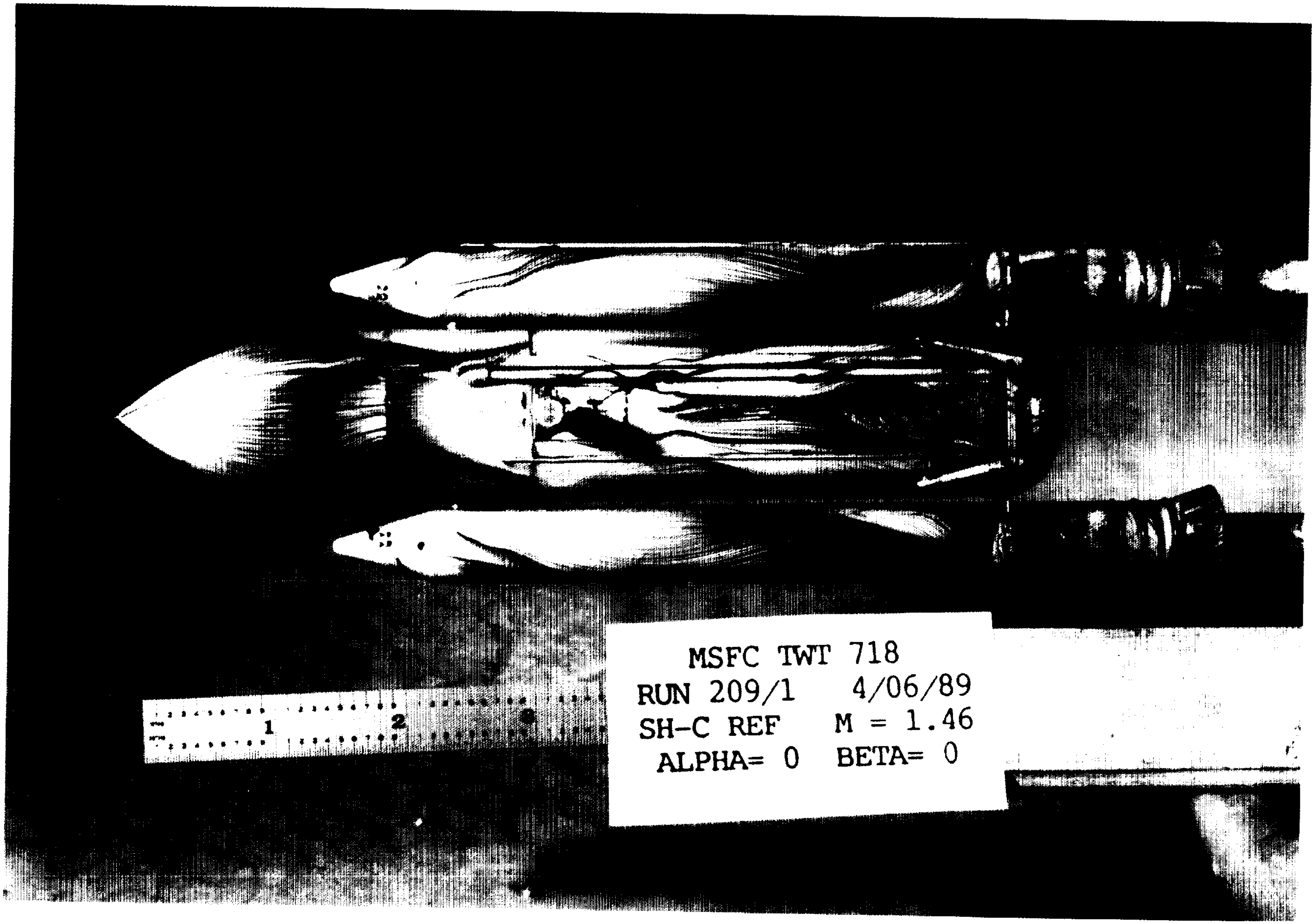


Figure 38. Shuttle-C lower stack Mach 1.46, alpha = 0, beta = 0, phi = 45.

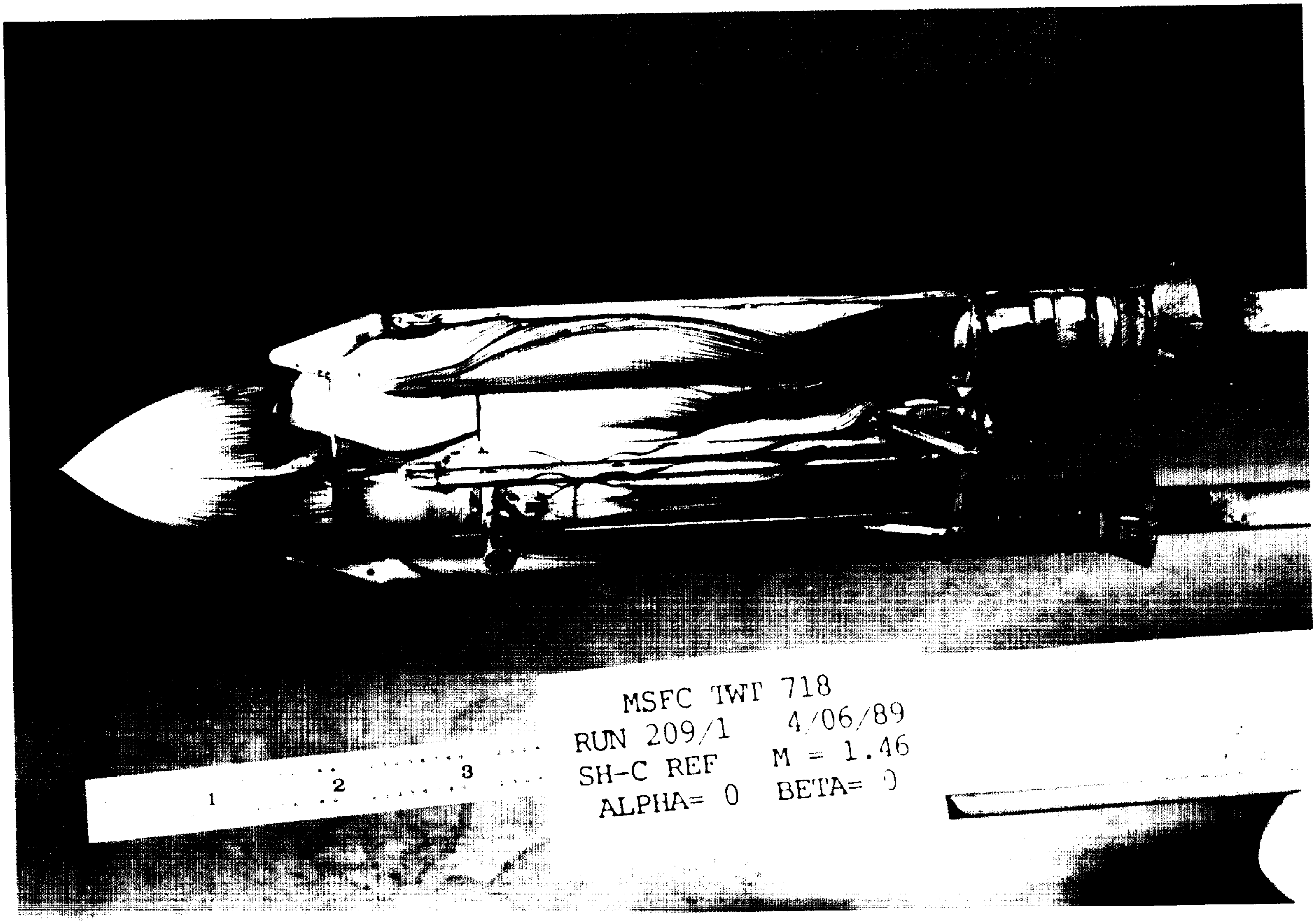


Figure 39. Shuttle-C lower stack Mach 1.46, alpha = 0, beta = 0, phi = 90.

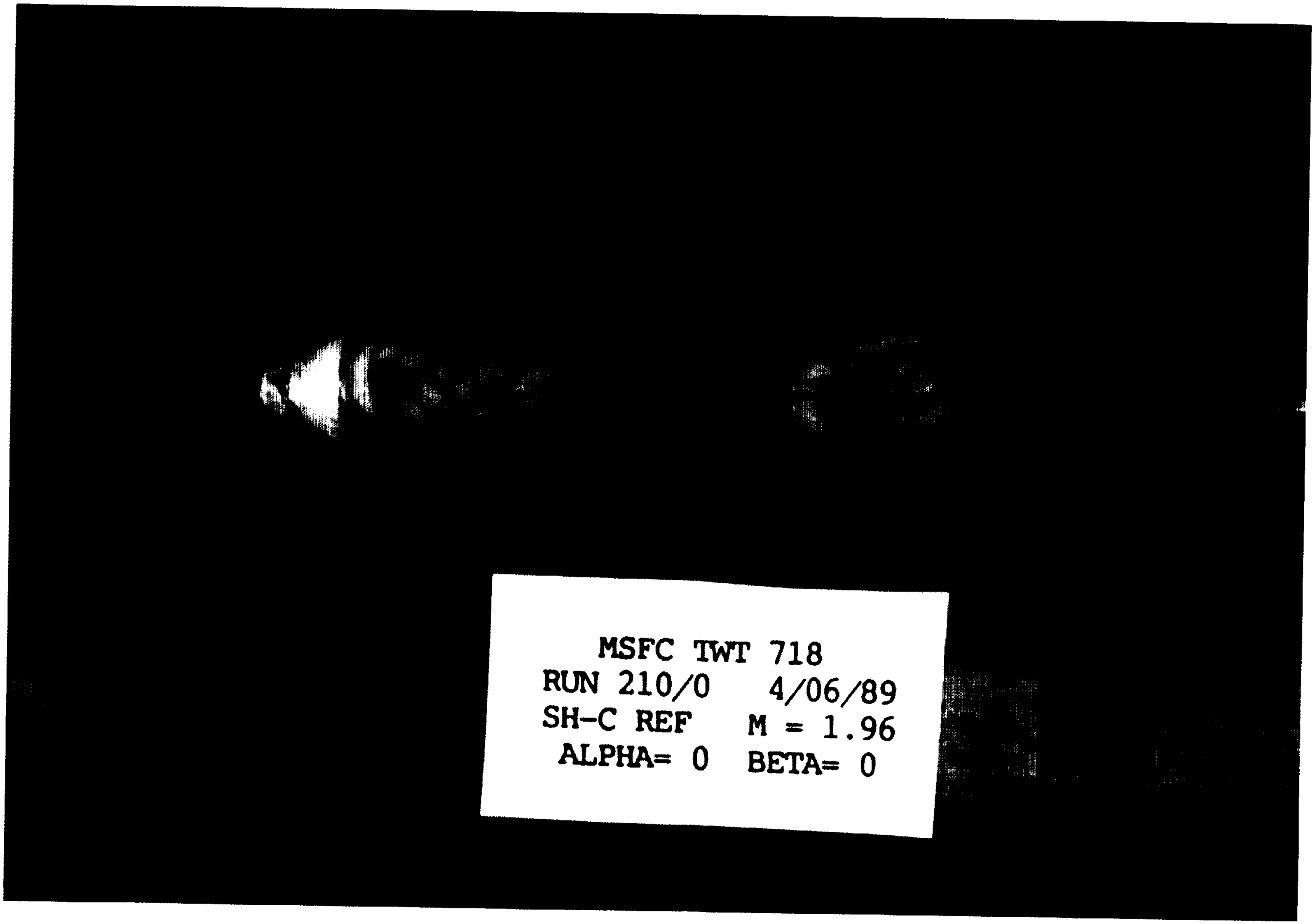


Figure 40. Shuttle-C cargo carrier Mach 1.96, alpha = 0, beta = 0, phi = 90.

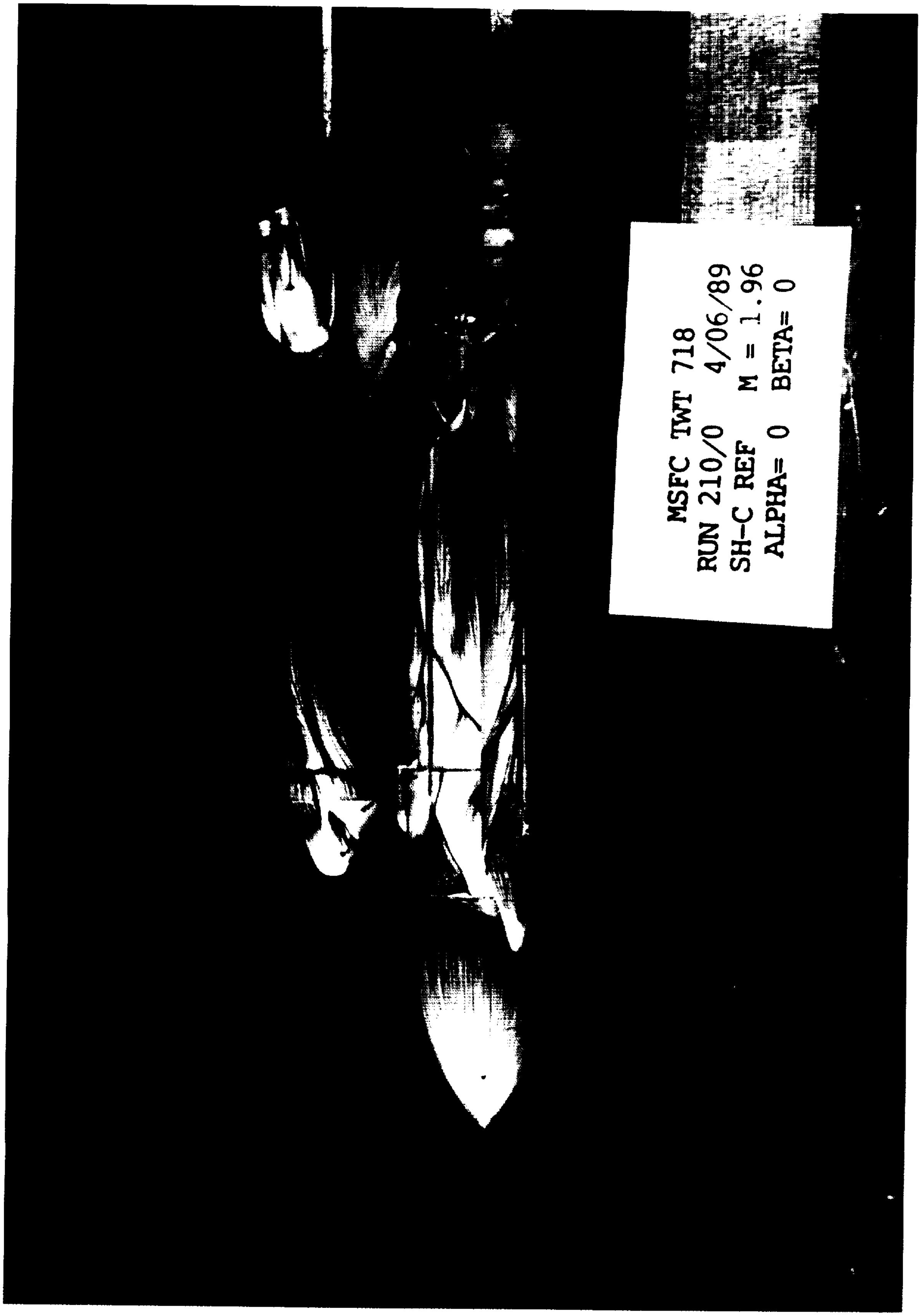


Figure 41. Shuttle-C mated vehicle Mach 1.96, alpha = 0, beta = 0, phi = 0.

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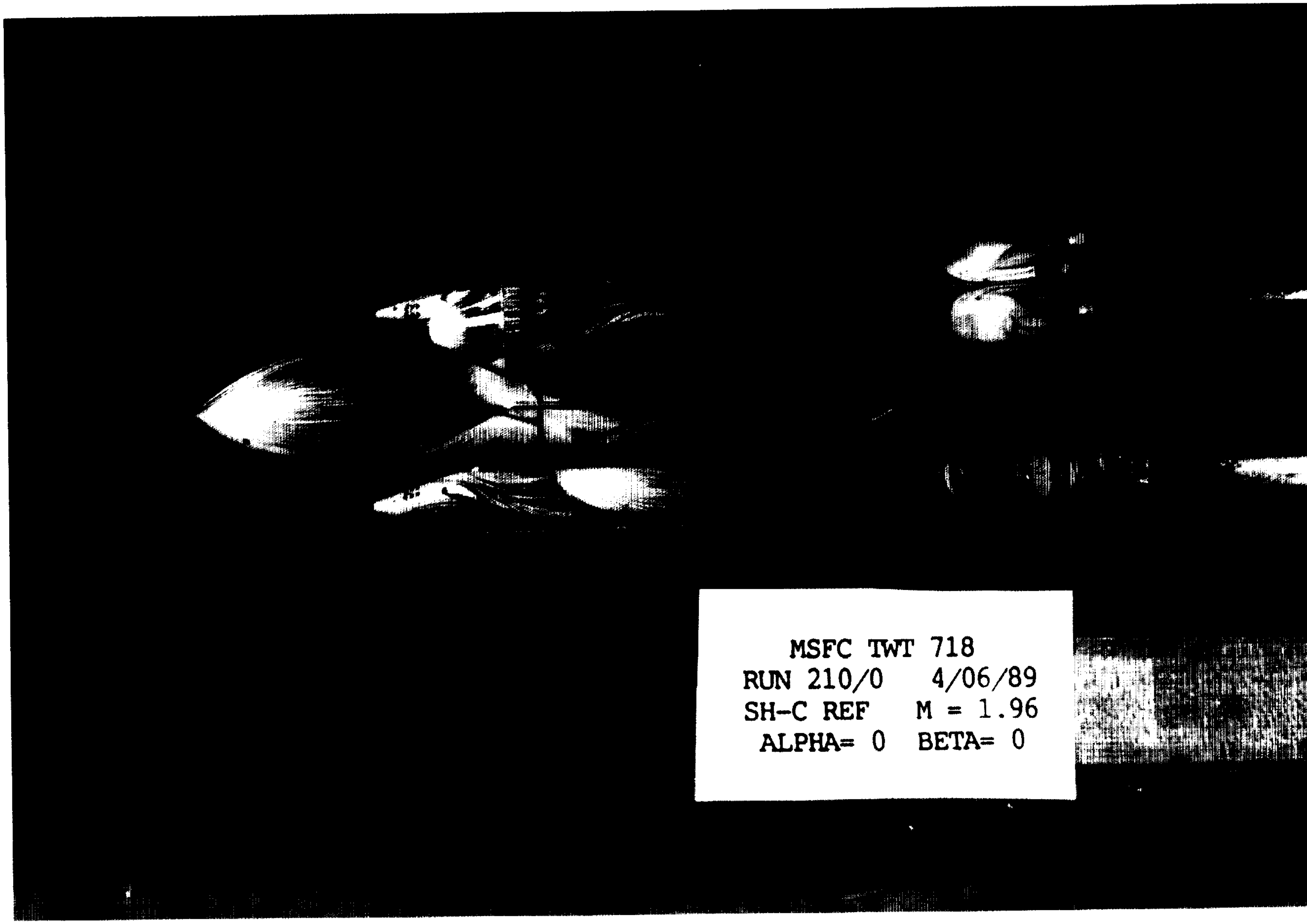
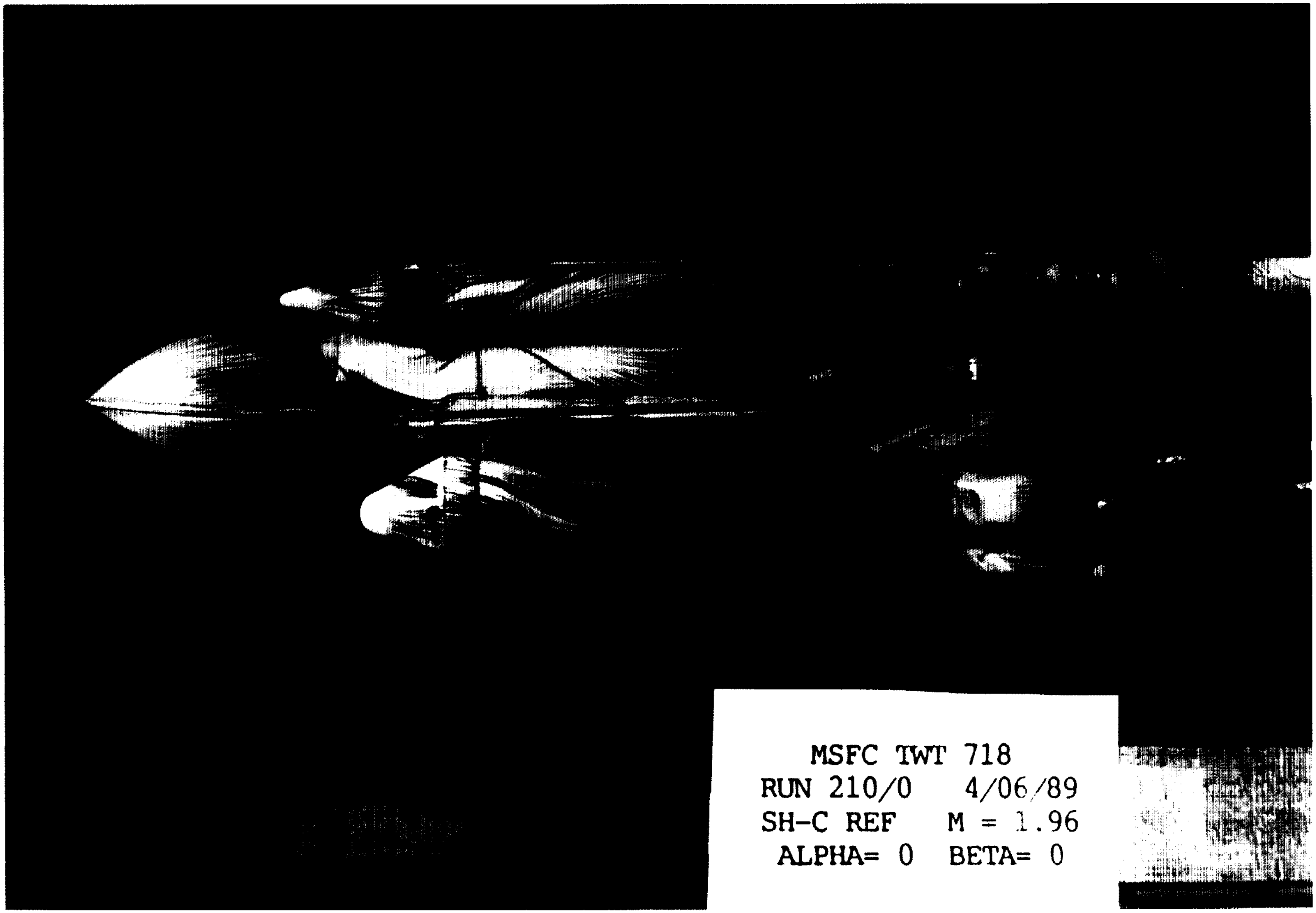



Figure 42. Shuttle-C mated vehicle Mach 1.96, alpha = 0, beta = 0, phi = 45.


Figure 43. Shuttle-C mated vehicle Mach 1.96, alpha = 0, beta = 0, phi = 90.

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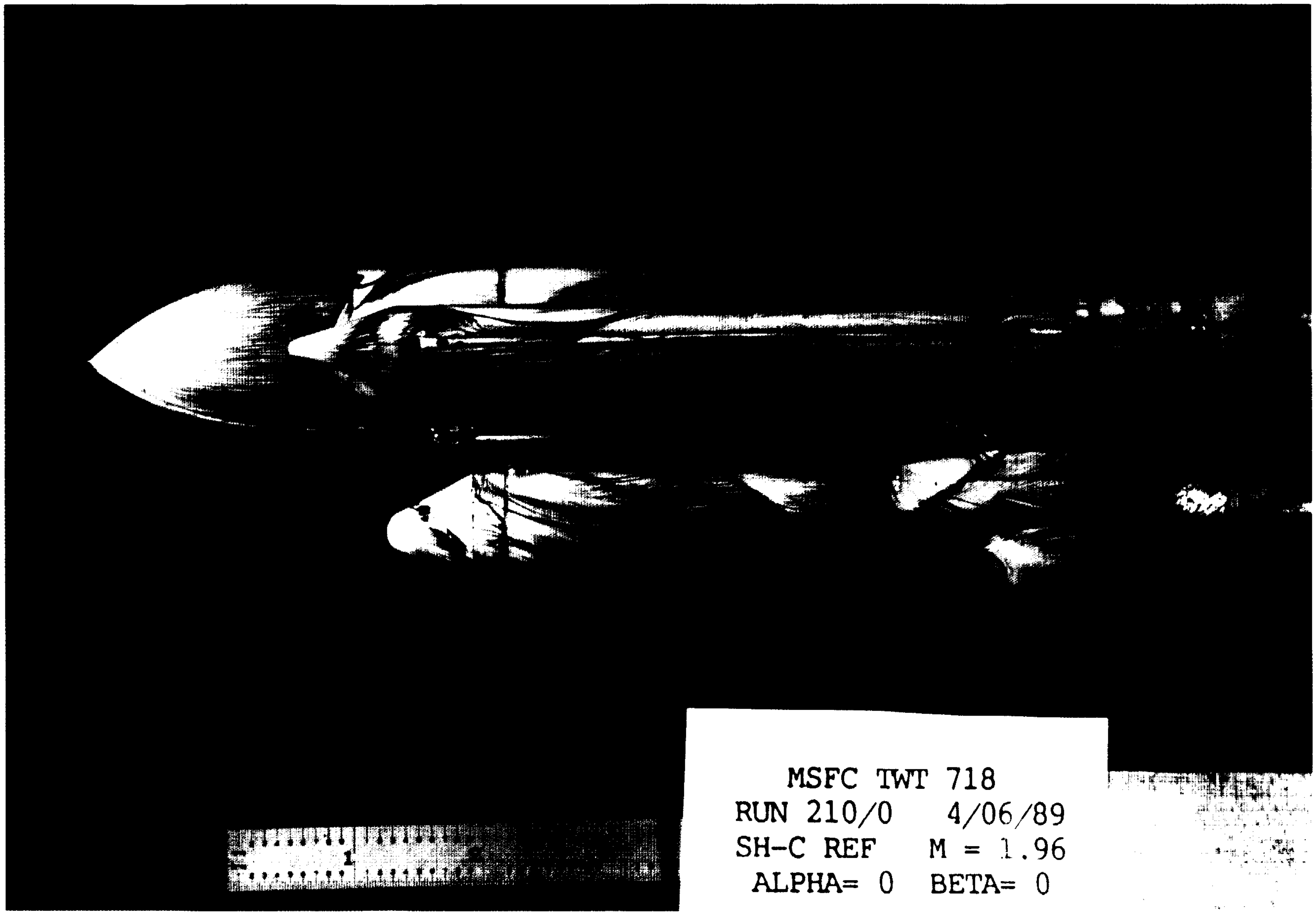



Figure 45. Shuttle-C mated vehicle Mach 1.96, alpha = 0, beta = 0, phi = 180.


Figure 46. Shuttle-C mated vehicle Mach 1.96, alpha = 0, beta = 0, phi = 225.

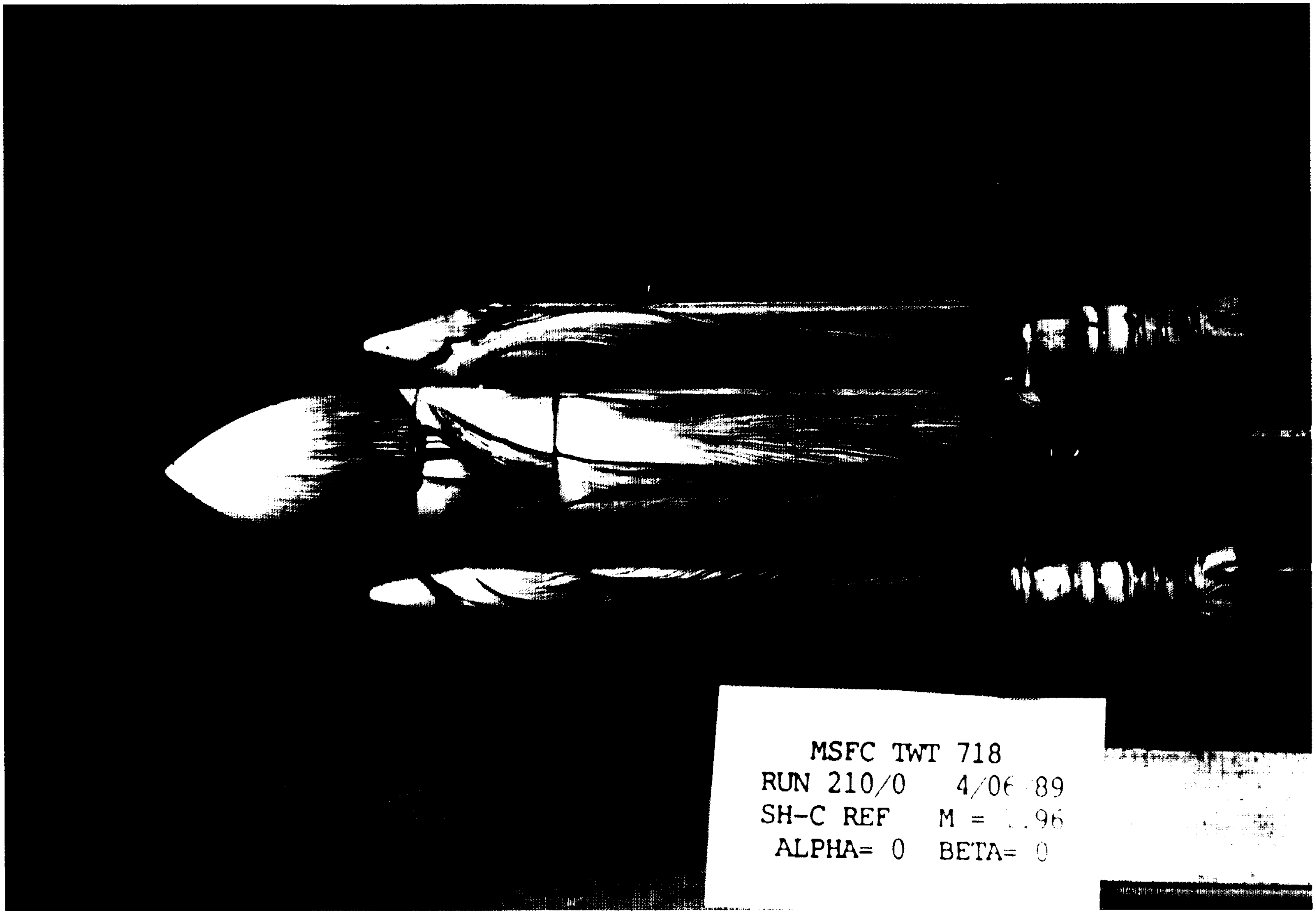



Figure 47. Shuttle-C mated vehicle Mach 1.96, alpha = 0, beta = 0, phi = 270.

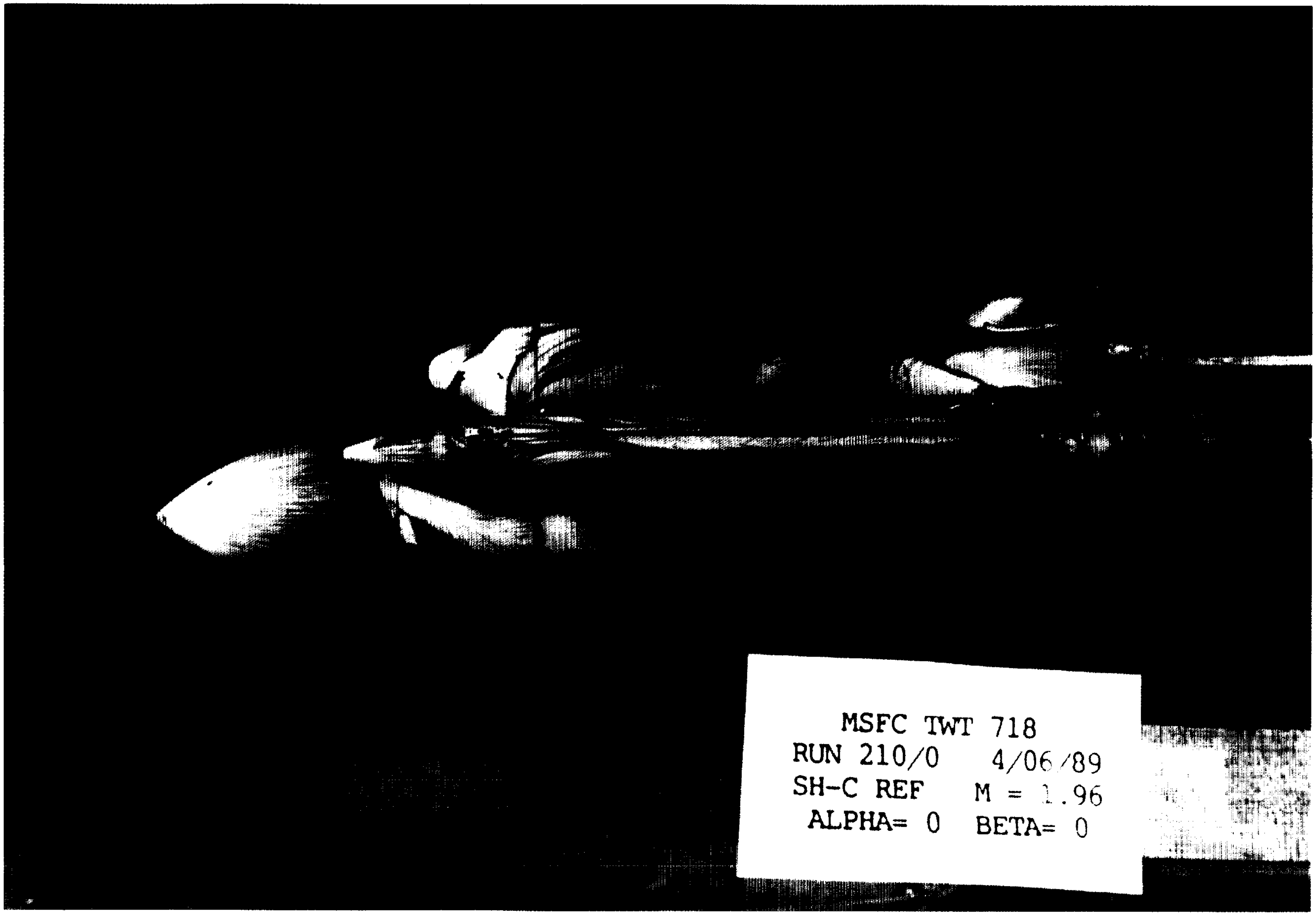



Figure 48. Shuttle-C mated vehicle Mach 1.96, alpha = 0, beta = 0, phi = 315.

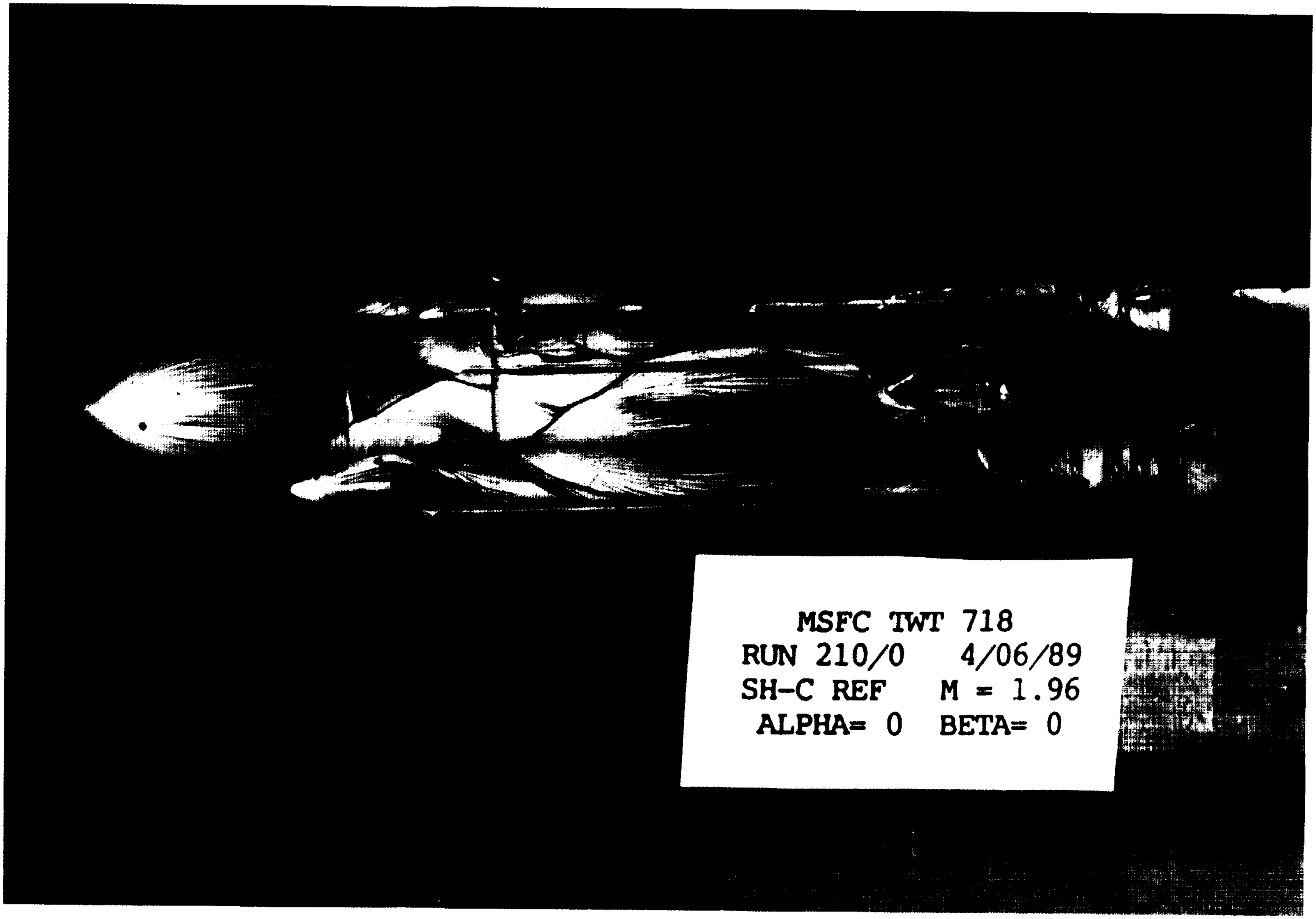



Figure 49. Shuttle-C lower stack Mach 1.96, alpha = 0, beta = 0, phi = 0.

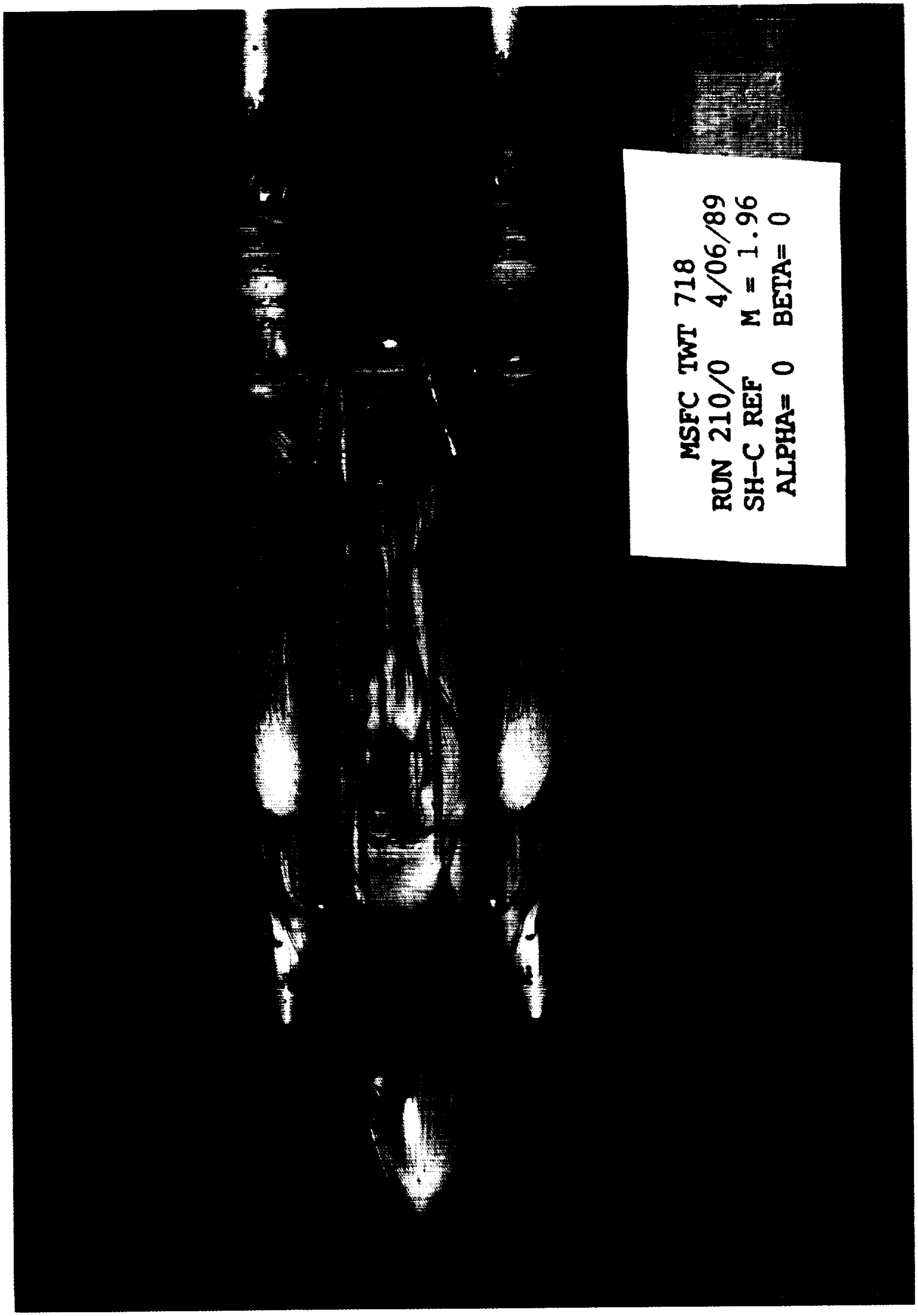



Figure 50. Shuttle-C lower stack Mach 1.96, alpha = 0, beta = 0, phi = 45.


Figure 51. Shuttle-C lower stack Mach 1.96, alpha = 0, beta = 0, phi = 90.

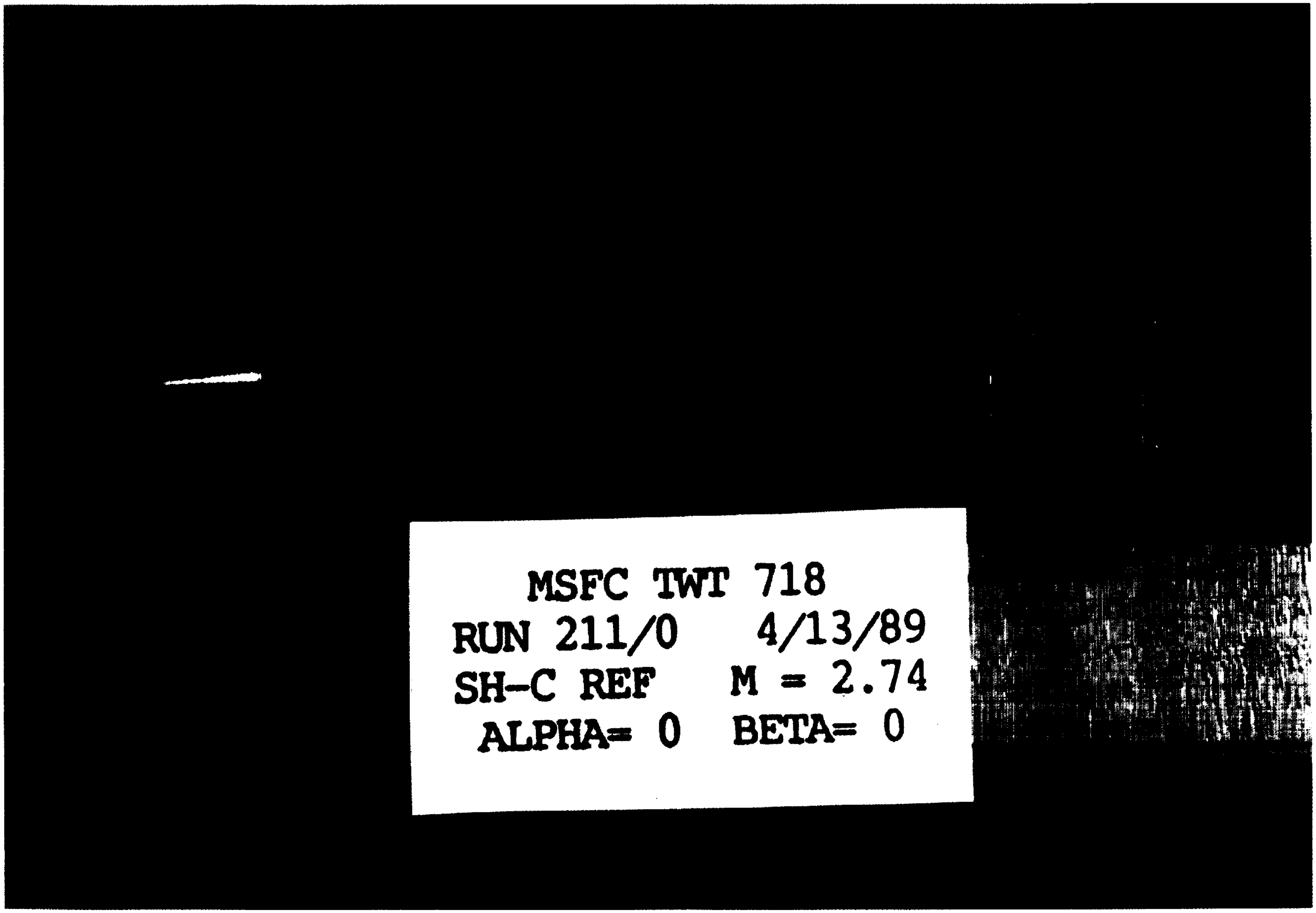



Figure 52. Shuttle-C cargo carrier Mach 2.74, alpha = 0, beta = 0, phi = 90.

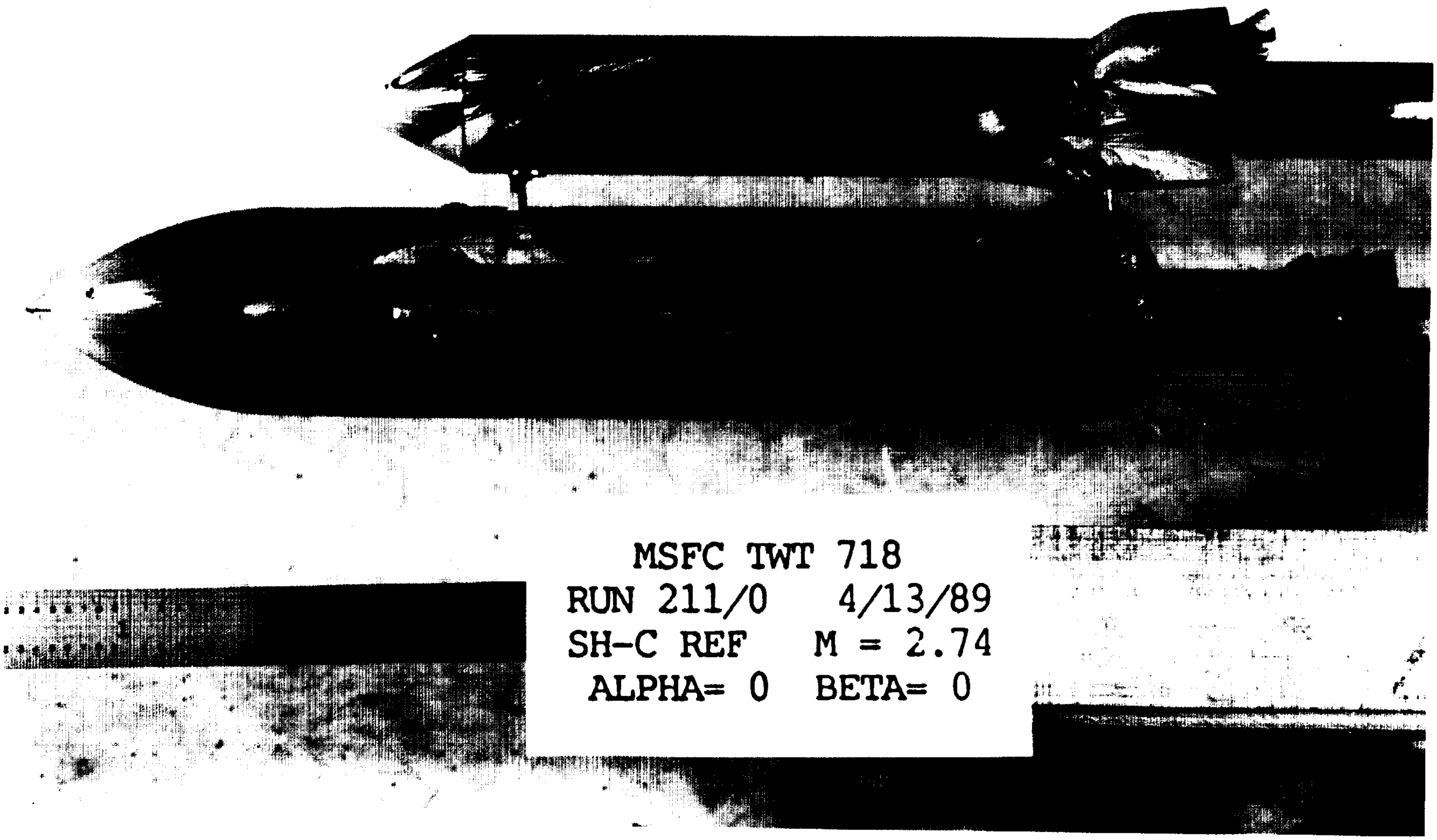



Figure 53. Shuttle-C mated vehicle Mach 2.74, alpha = 0, beta = 0, phi = 0.

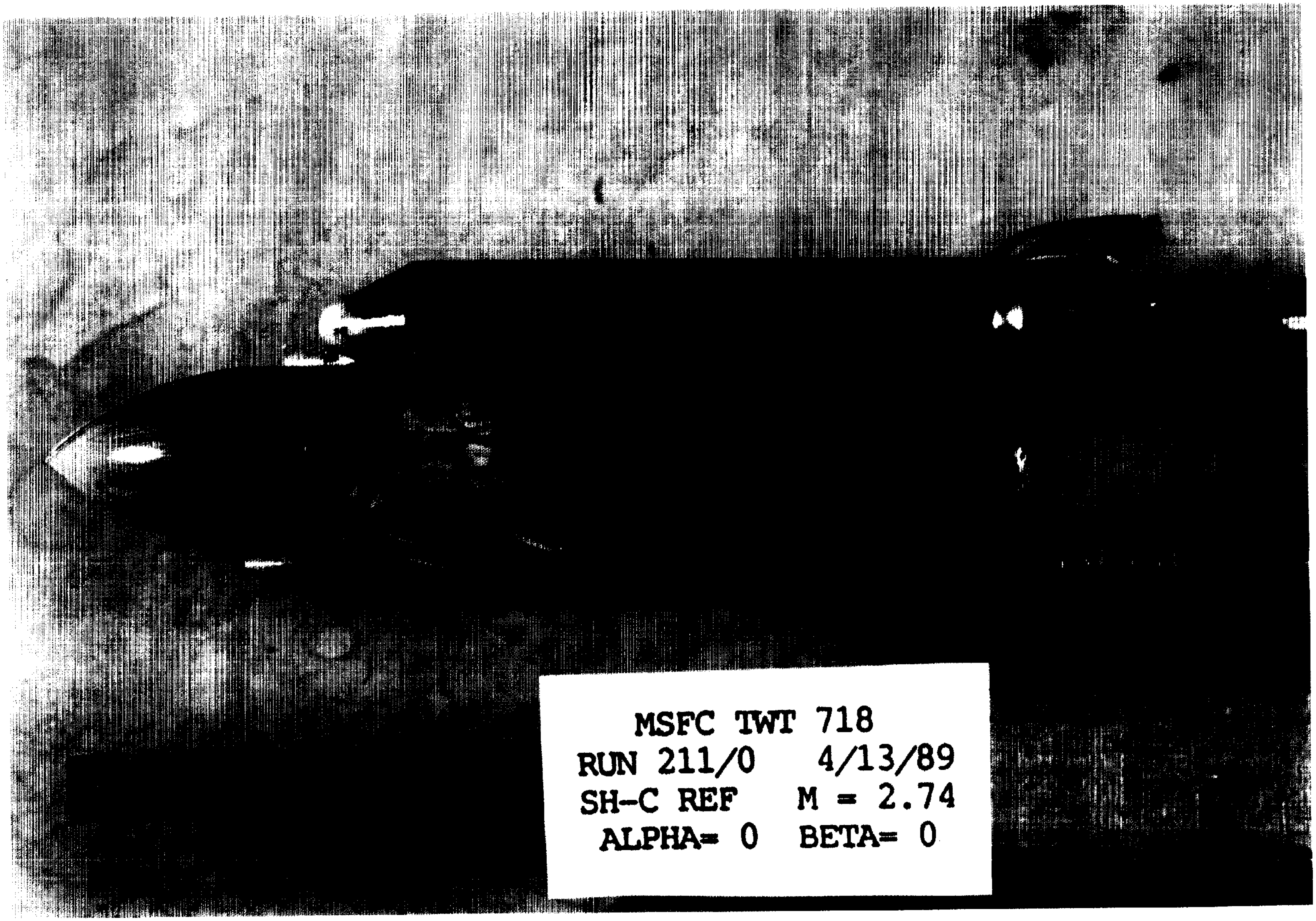
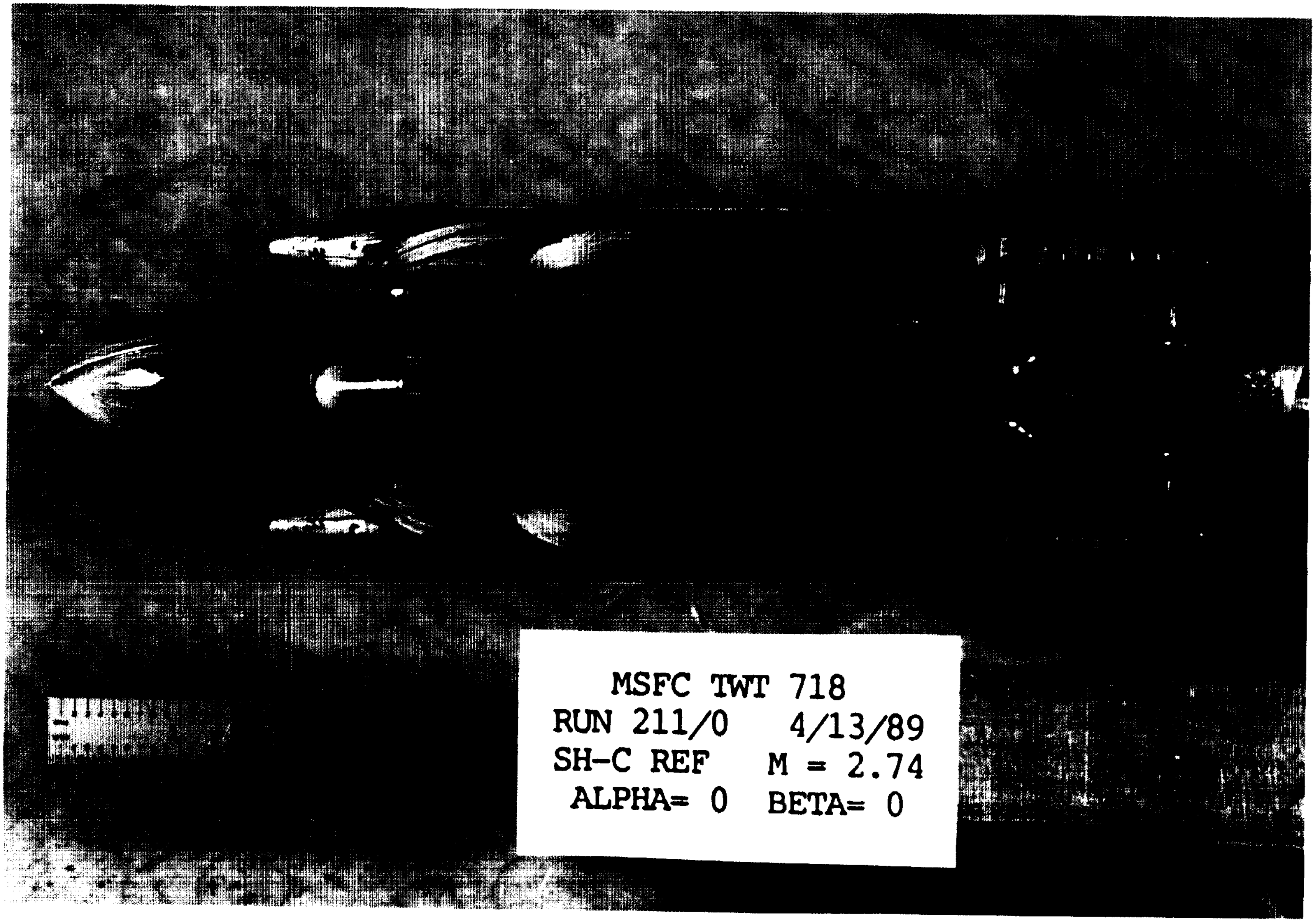



Figure 54. Shuttle-C mated vehicle Mach 2.74, alpha = 0, beta = 0, phi = 45.

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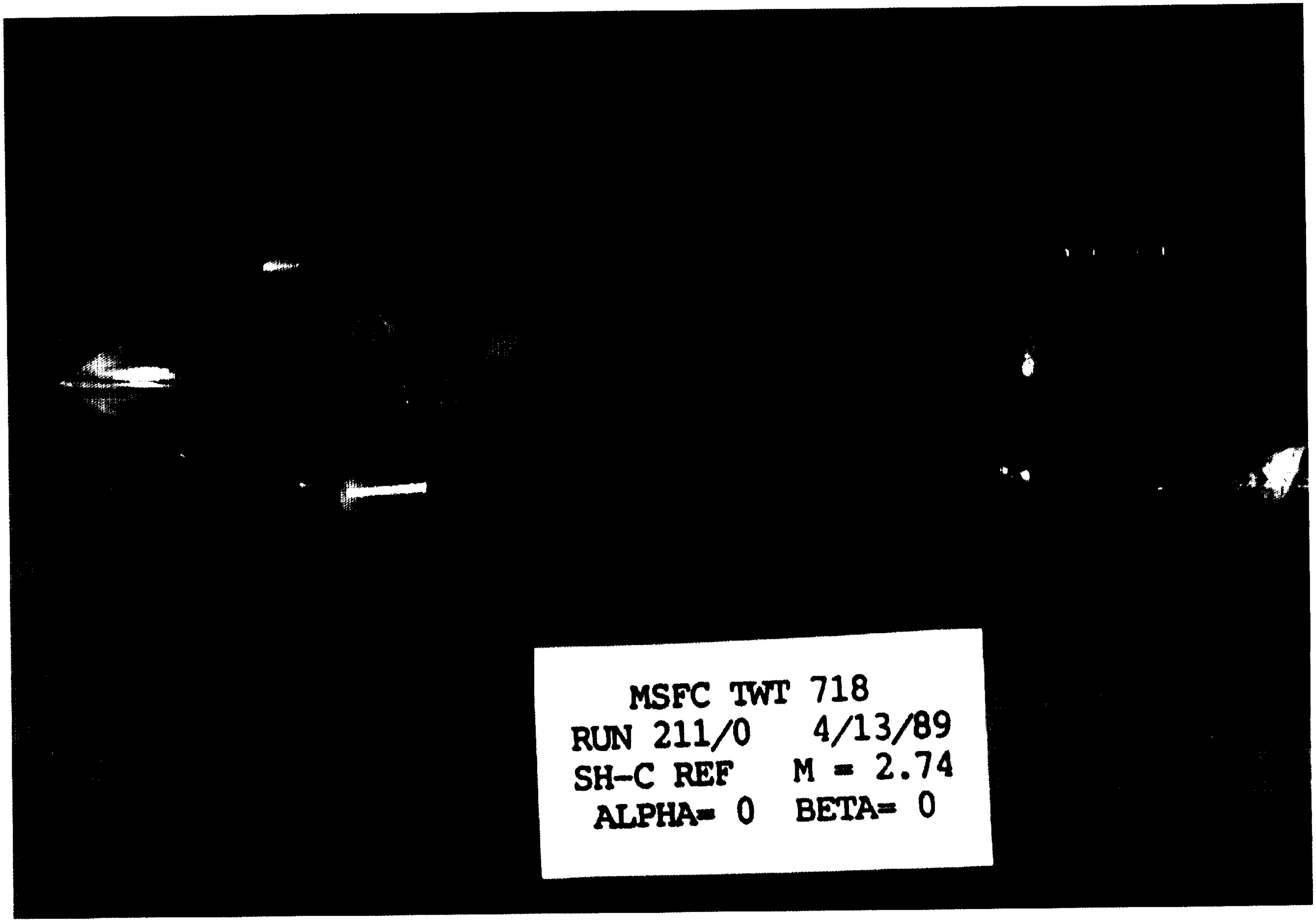



Figure 56. Shuttle-C mated vehicle Mach 2.74, alpha = 0, beta = 0, phi = 135.

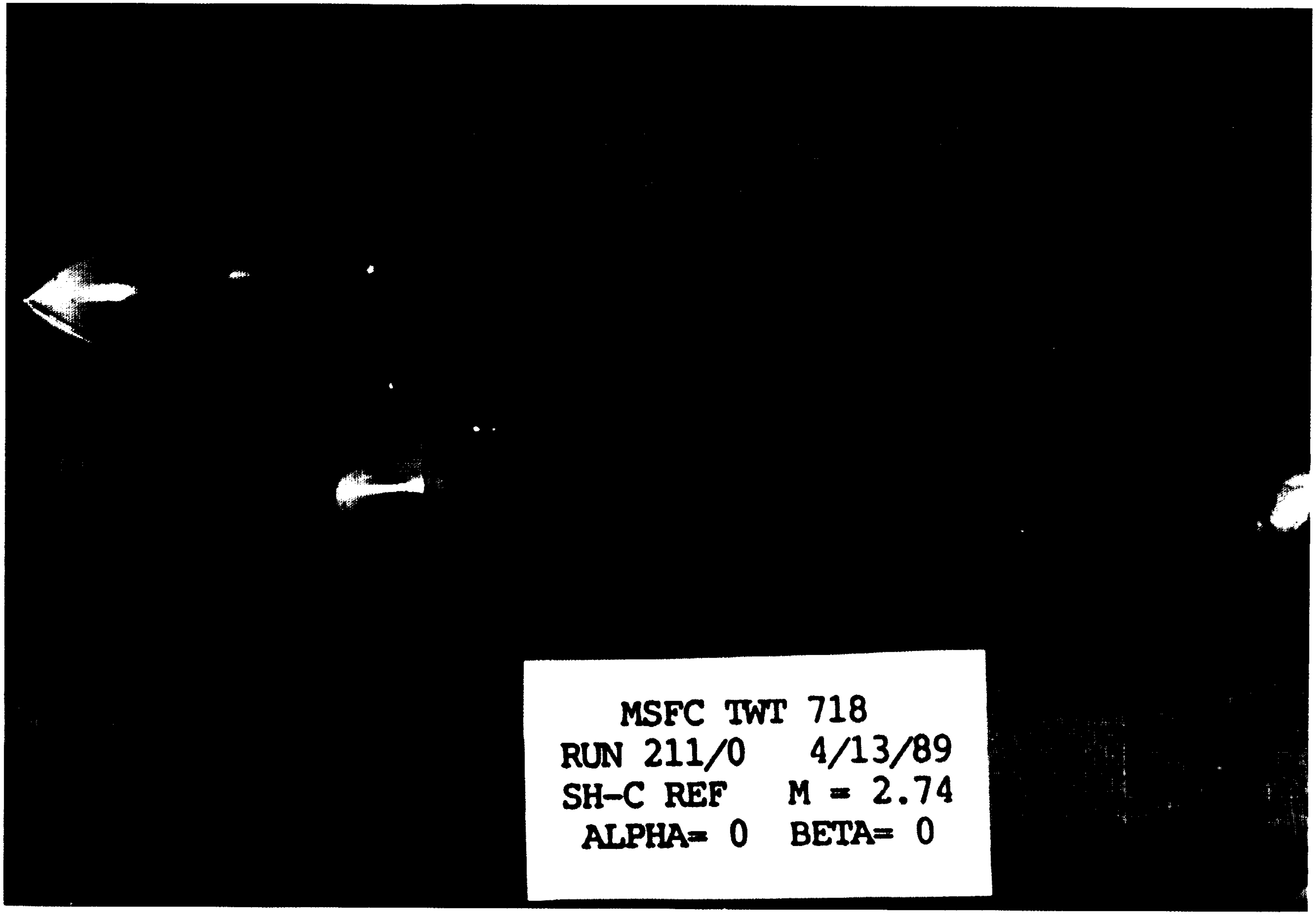



Figure 57. Shuttle-C mated vehicle Mach 2.74, alpha = 0, beta = 0, phi = 180.

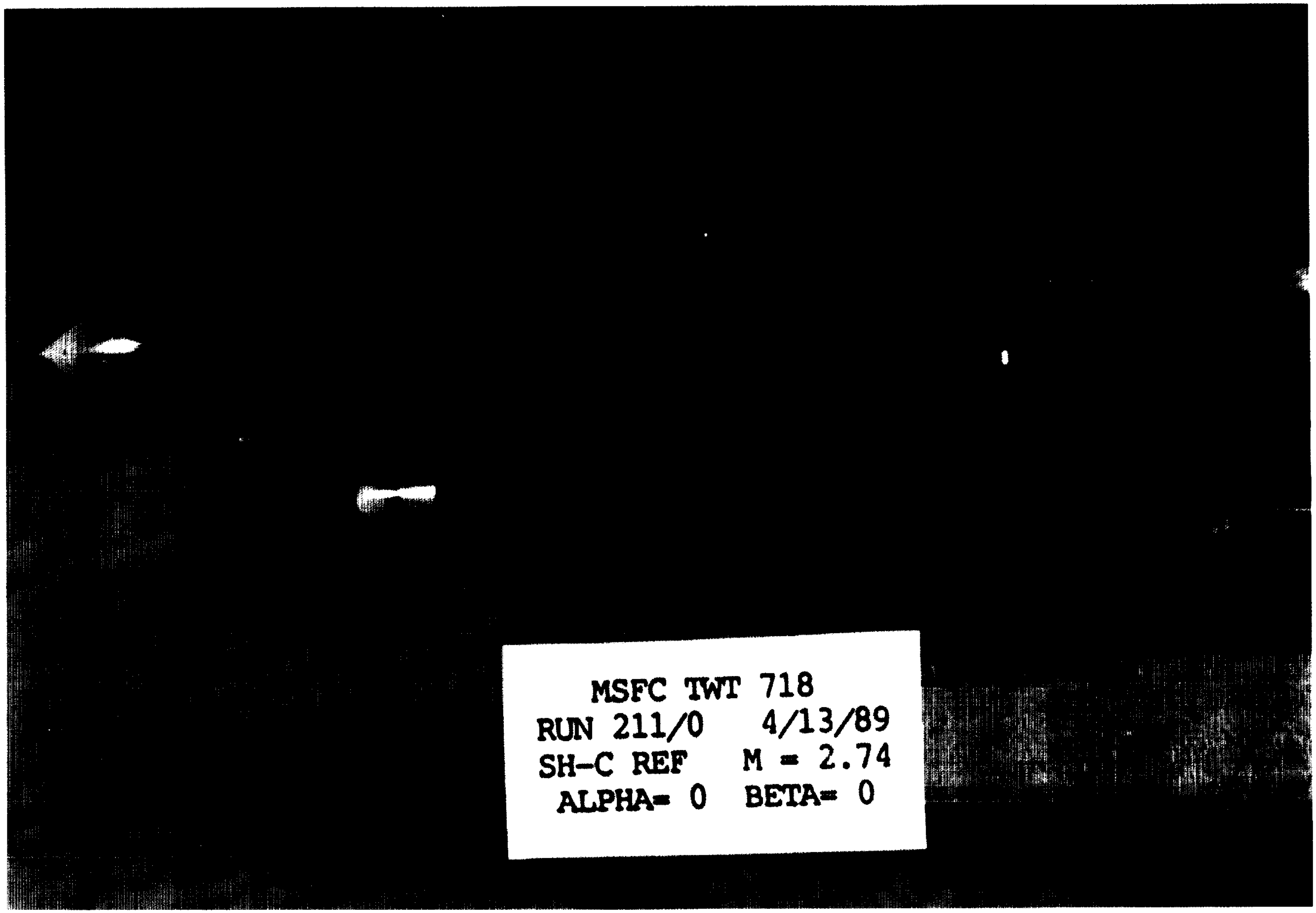



Figure 58. Shuttle-C mated vehicle Mach 2.74, alpha = 0, beta = 0, phi = 225.

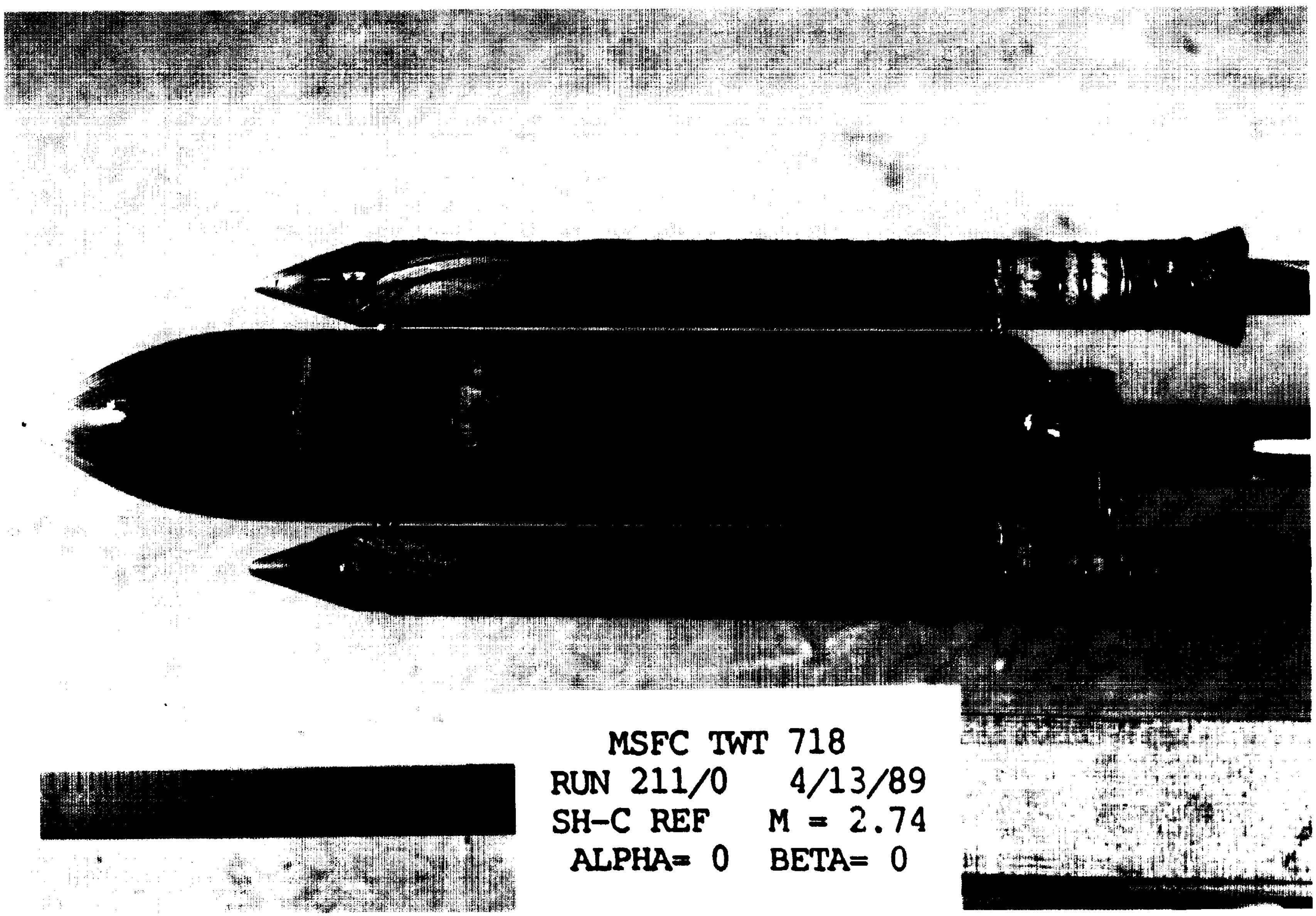



Figure 59. Shuttle-C mated vehicle Mach 2.74, alpha = 0, beta = 0, phi = 270.

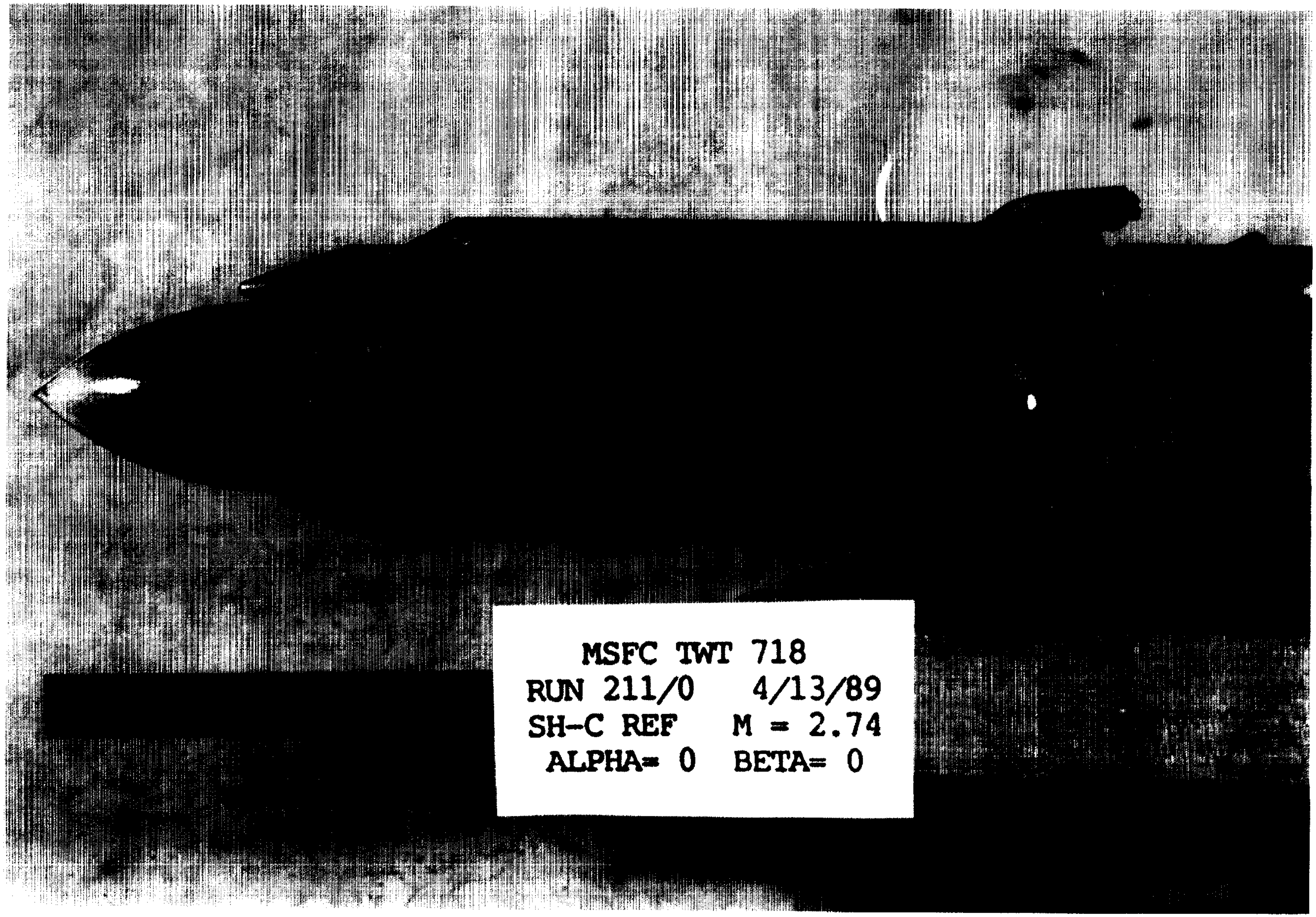
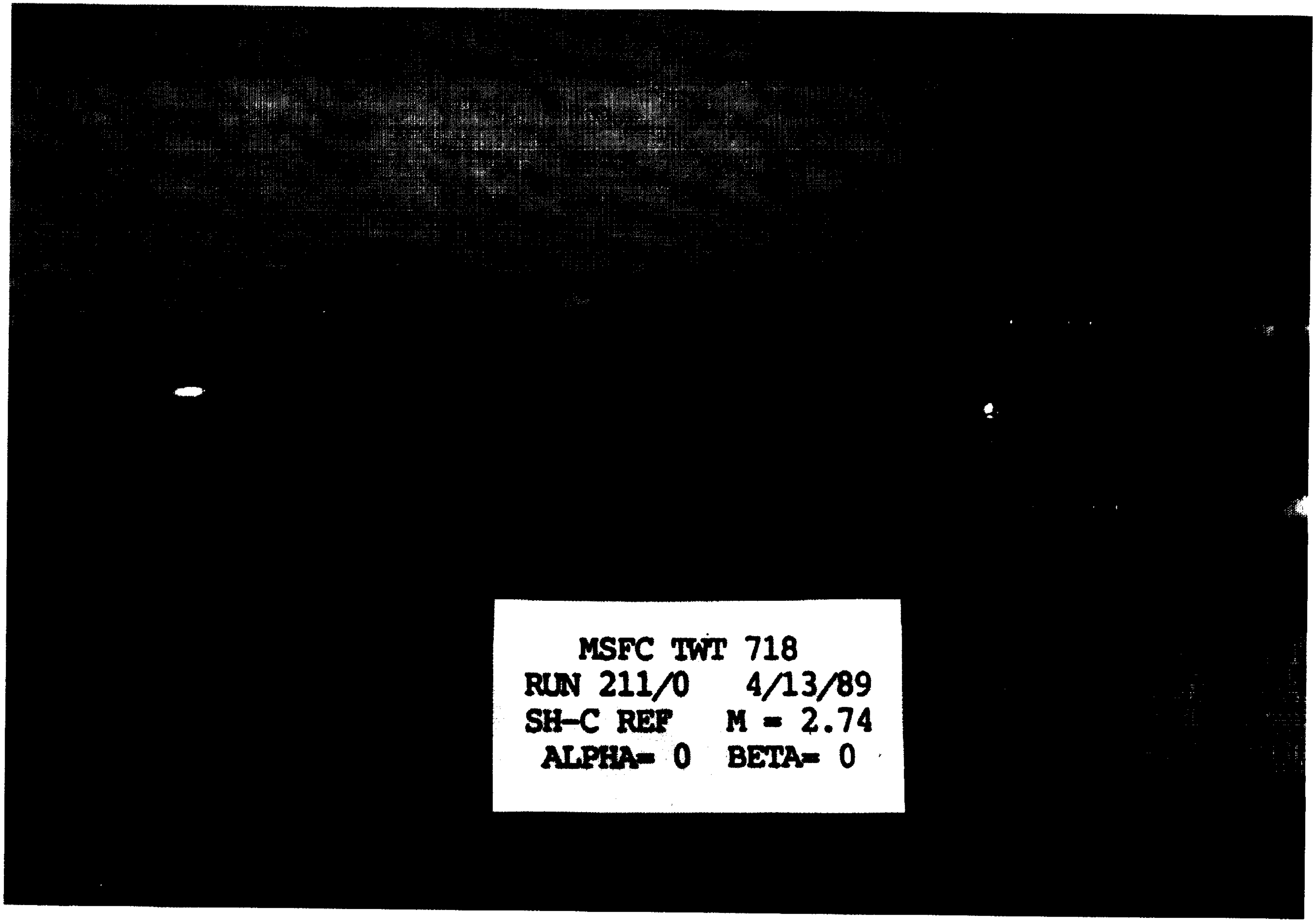



Figure 60. Shuttle-C mated vehicle Mach 2.74, alpha = 0, beta = 0, phi = 315.

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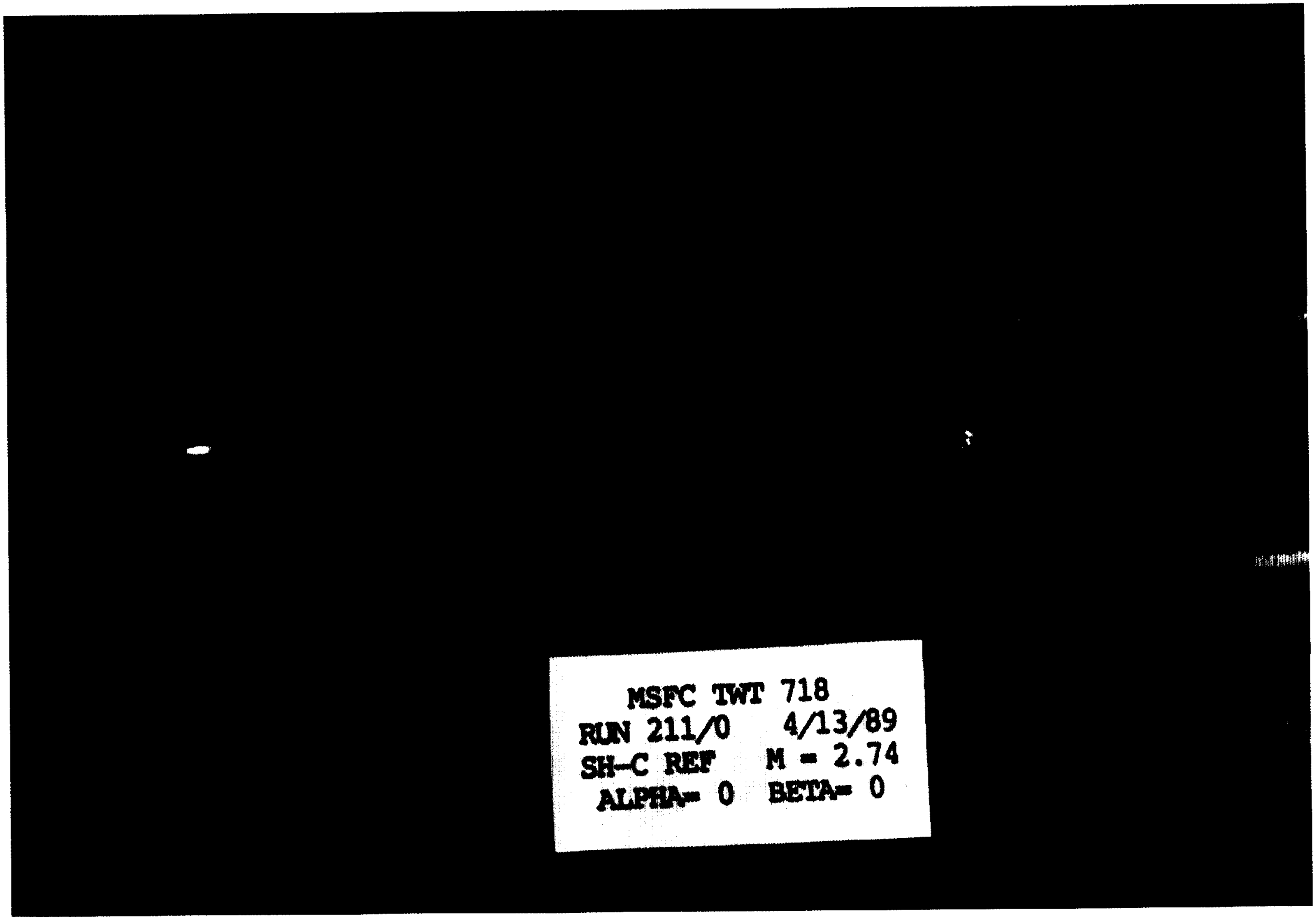


Figure 62. Shuttle-C lower stack Mach 2.74, alpha = 0, beta = 0, phi = 45.

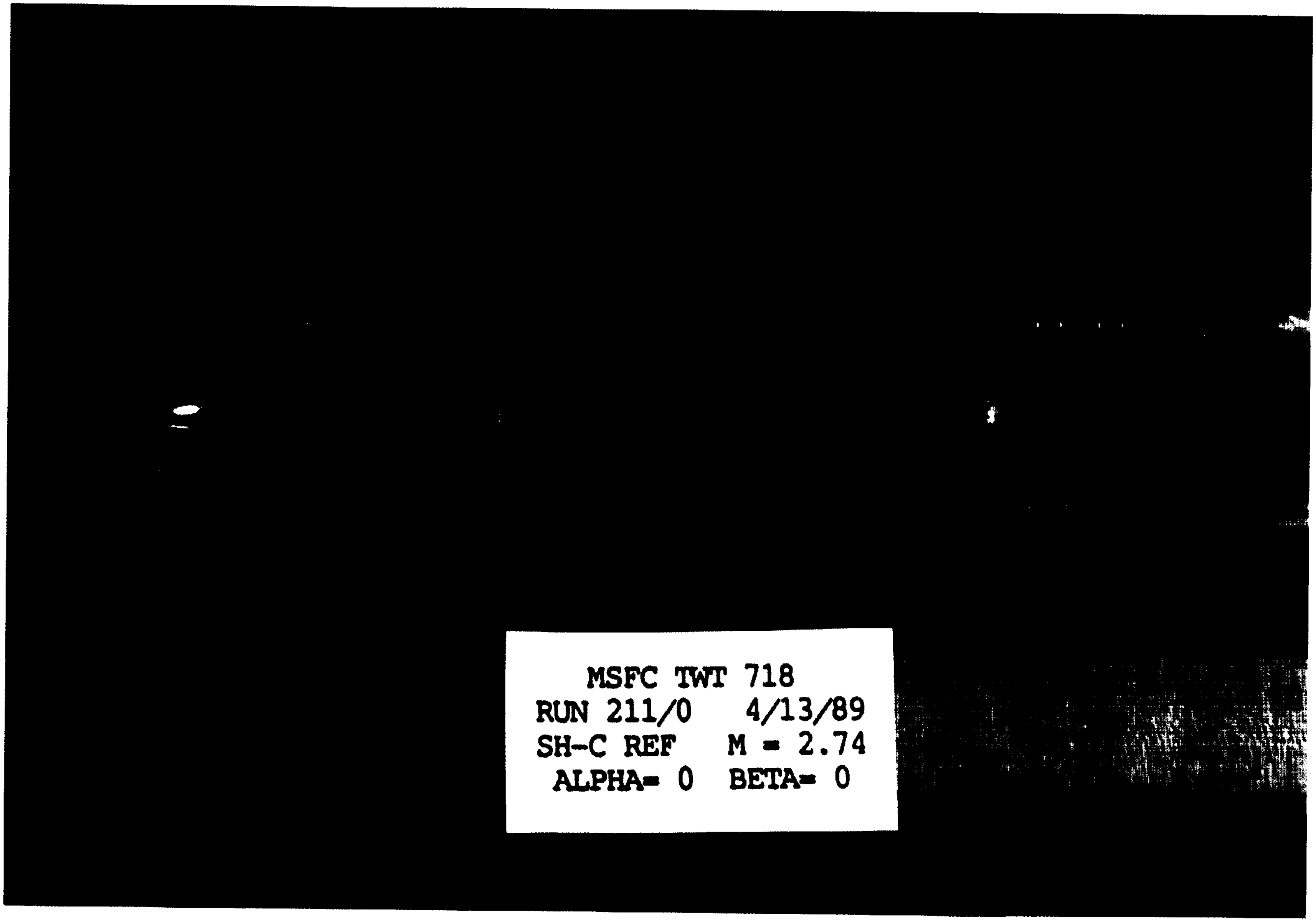


Figure 63. Shuttle-C lower stack Mach 2.74, alpha = 0, beta = 0, phi = 90.

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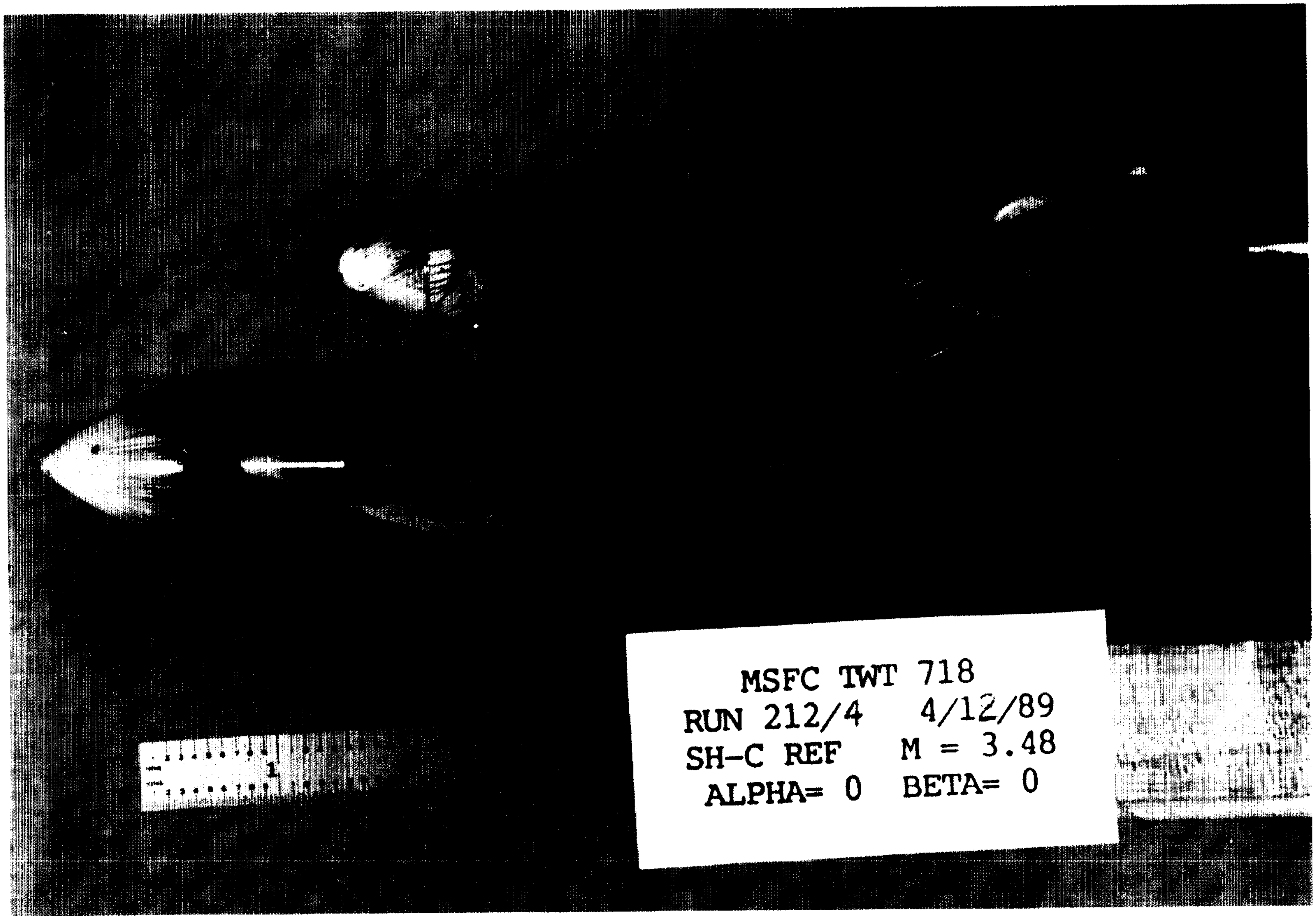



Figure 64. Shuttle-C mated vehicle Mach 3.48, alpha = 0, beta = 0, phi = 0.

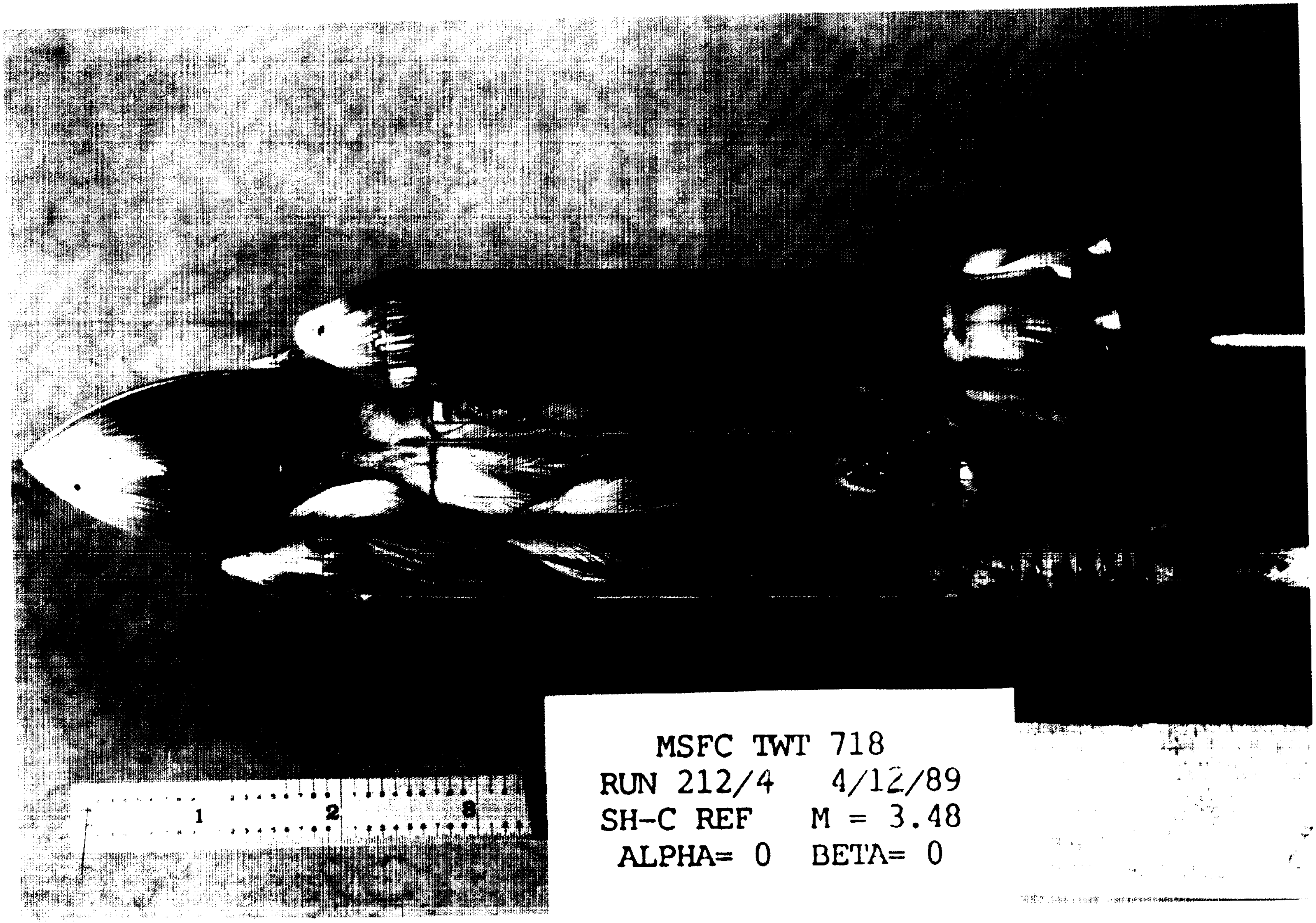
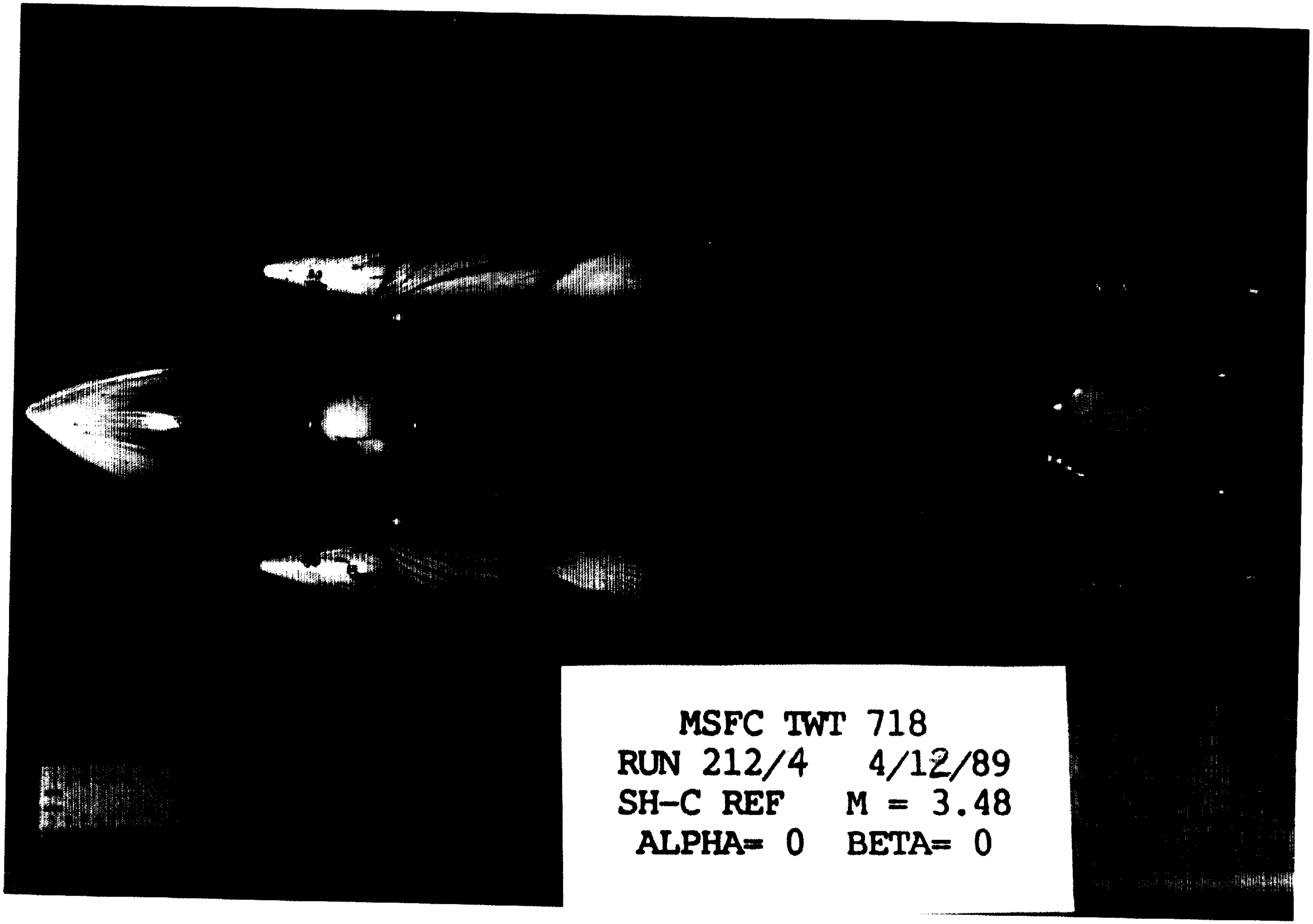



Figure 65. Shuttle-C mated vehicle Mach 3.48, alpha = 0, beta = 0, phi = 45.

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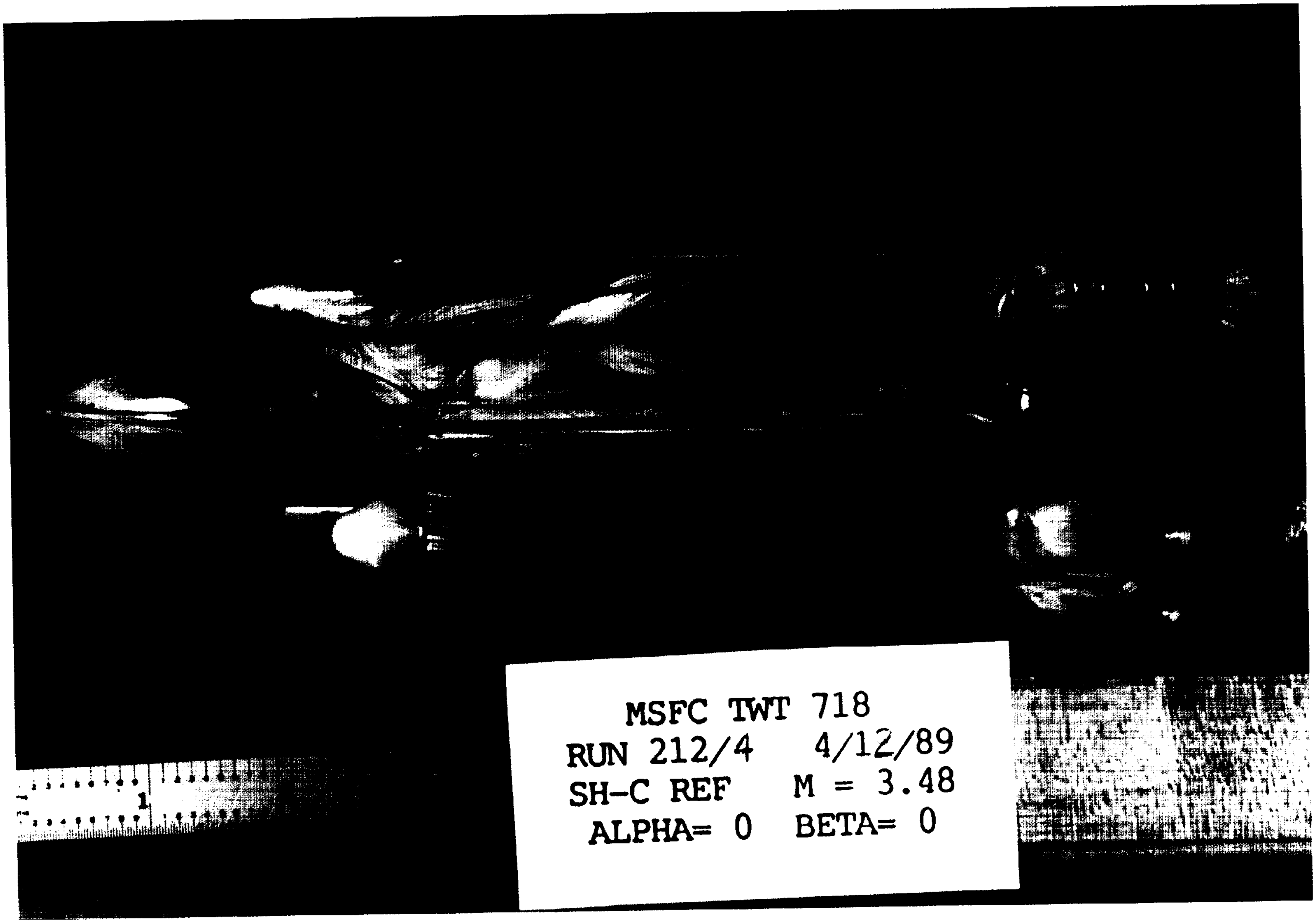


Figure 67. Shuttle-C mated vehicle Mach 3.48, alpha = 0, beta = 0, phi = 135.

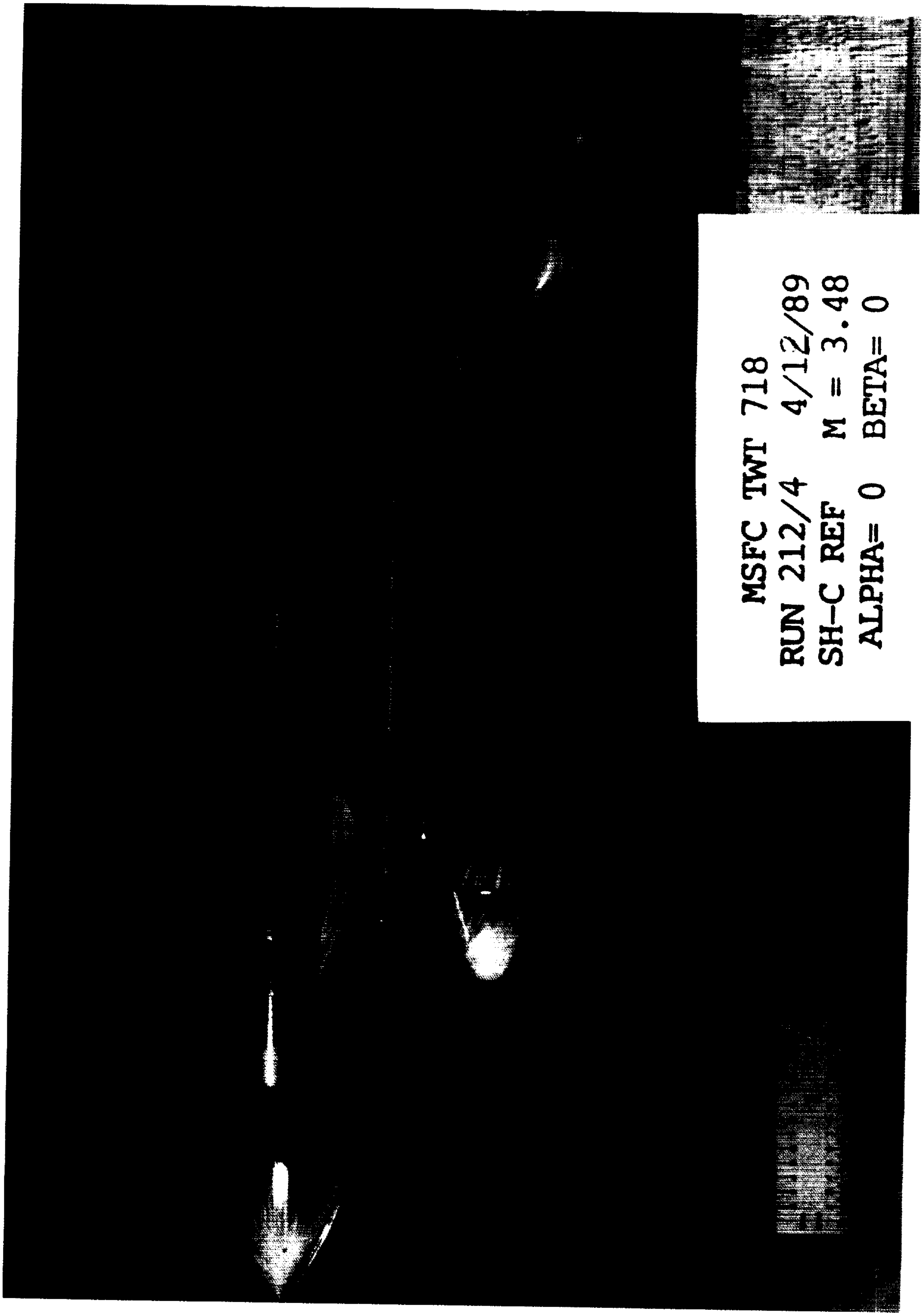


Figure 68. Shuttle-C mated vehicle Mach 3.48, alpha = 0, beta = 0, phi = 180.



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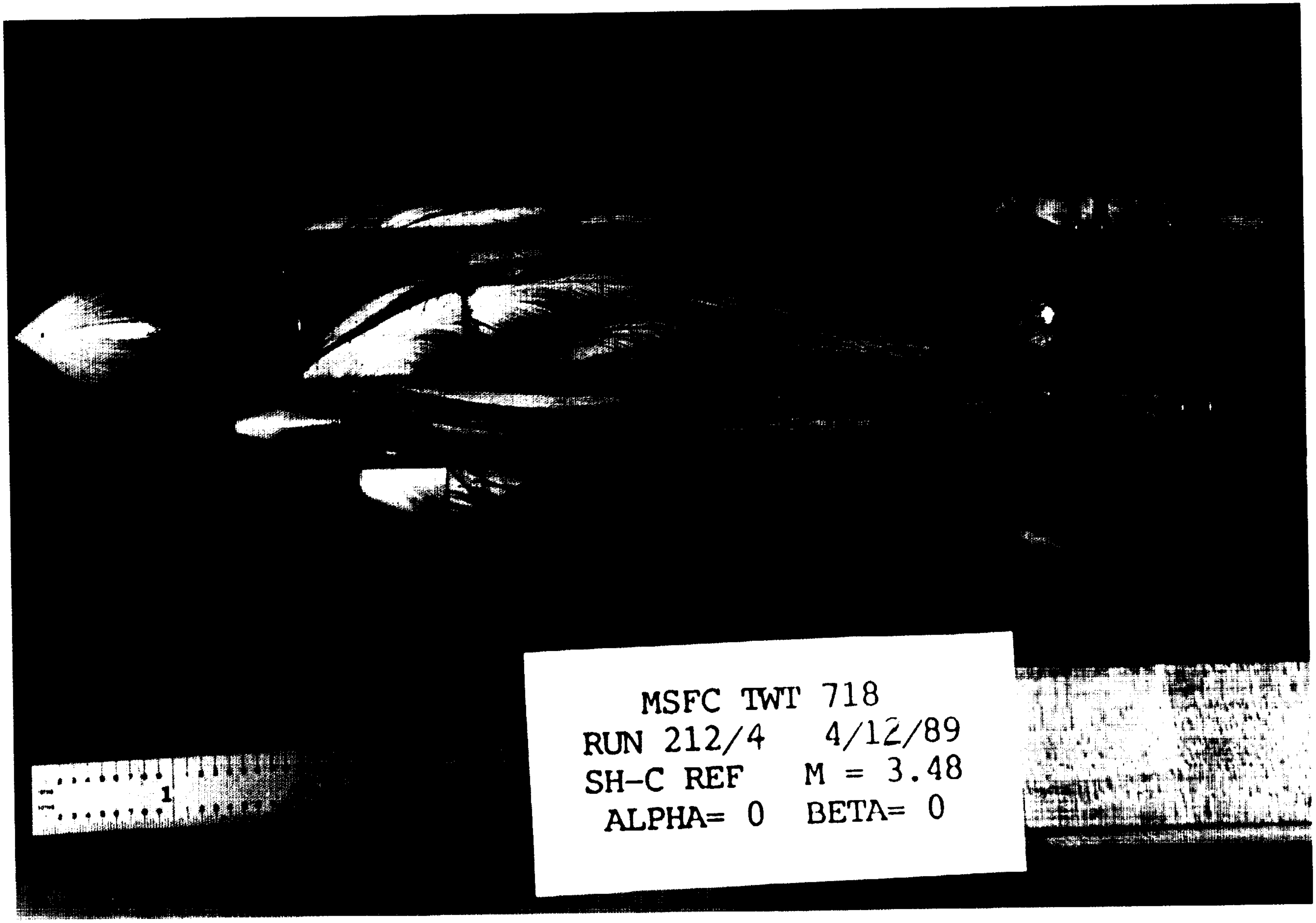


Figure 69. Shuttle-C mated vehicle Mach 3.48, alpha = 0, beta = 0, phi = 225.

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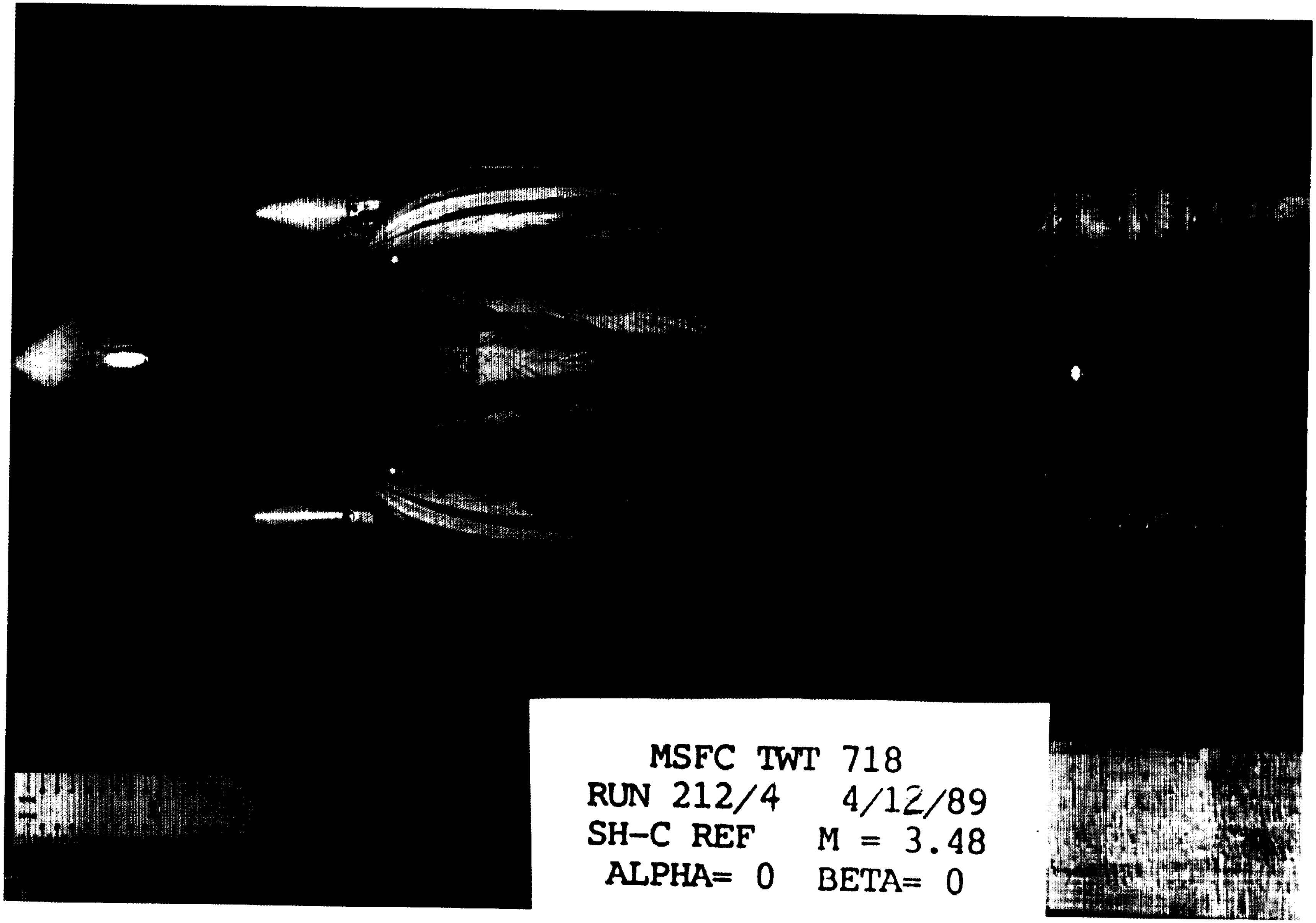


Figure 70. Shuttle-C mated vehicle Mach 3.48, alpha = 0, beta = 0, phi = 270.

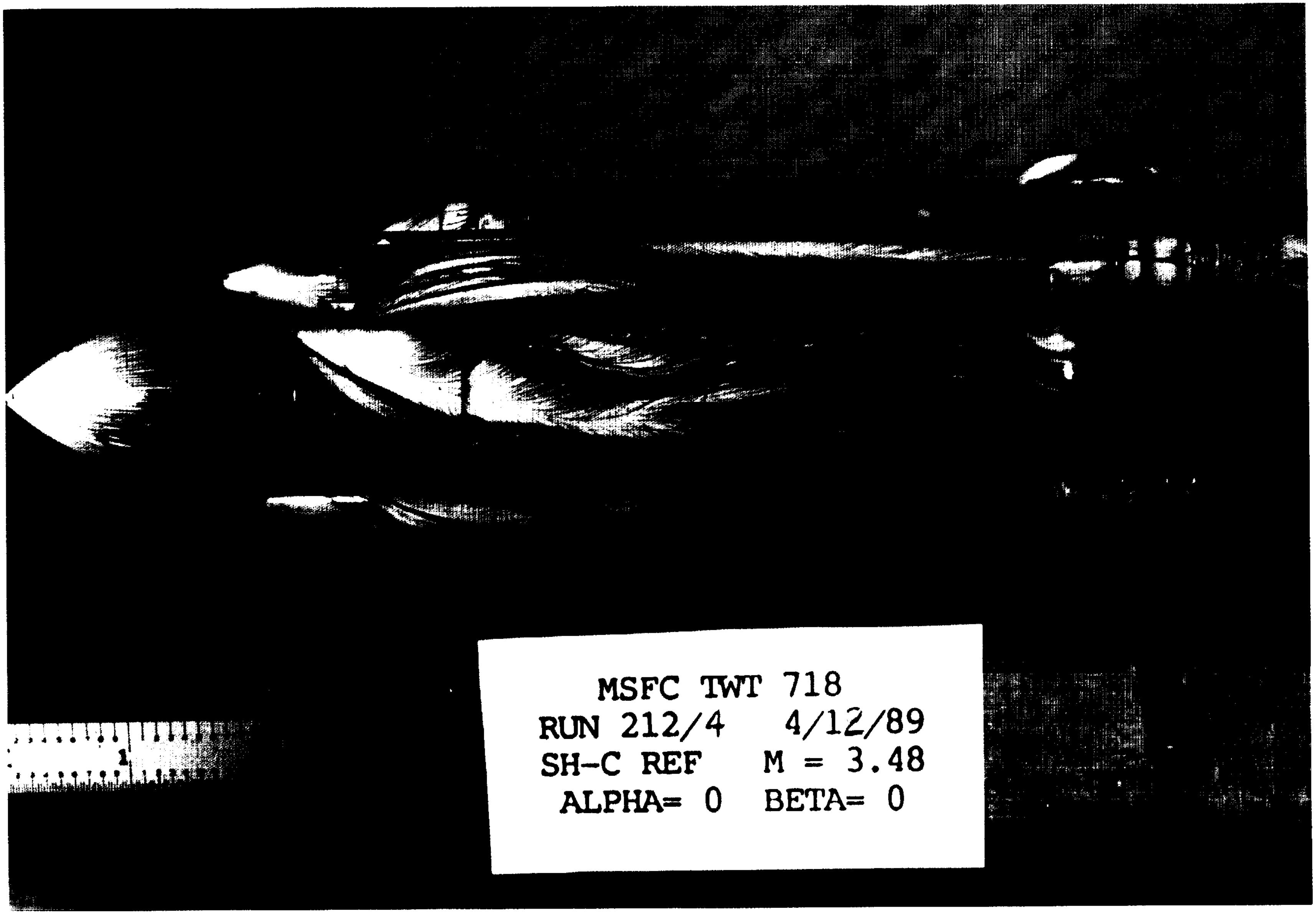


Figure 71. Shuttle-C mated vehicle Mach 3.48, alpha = 0, beta = 0, phi = 315.

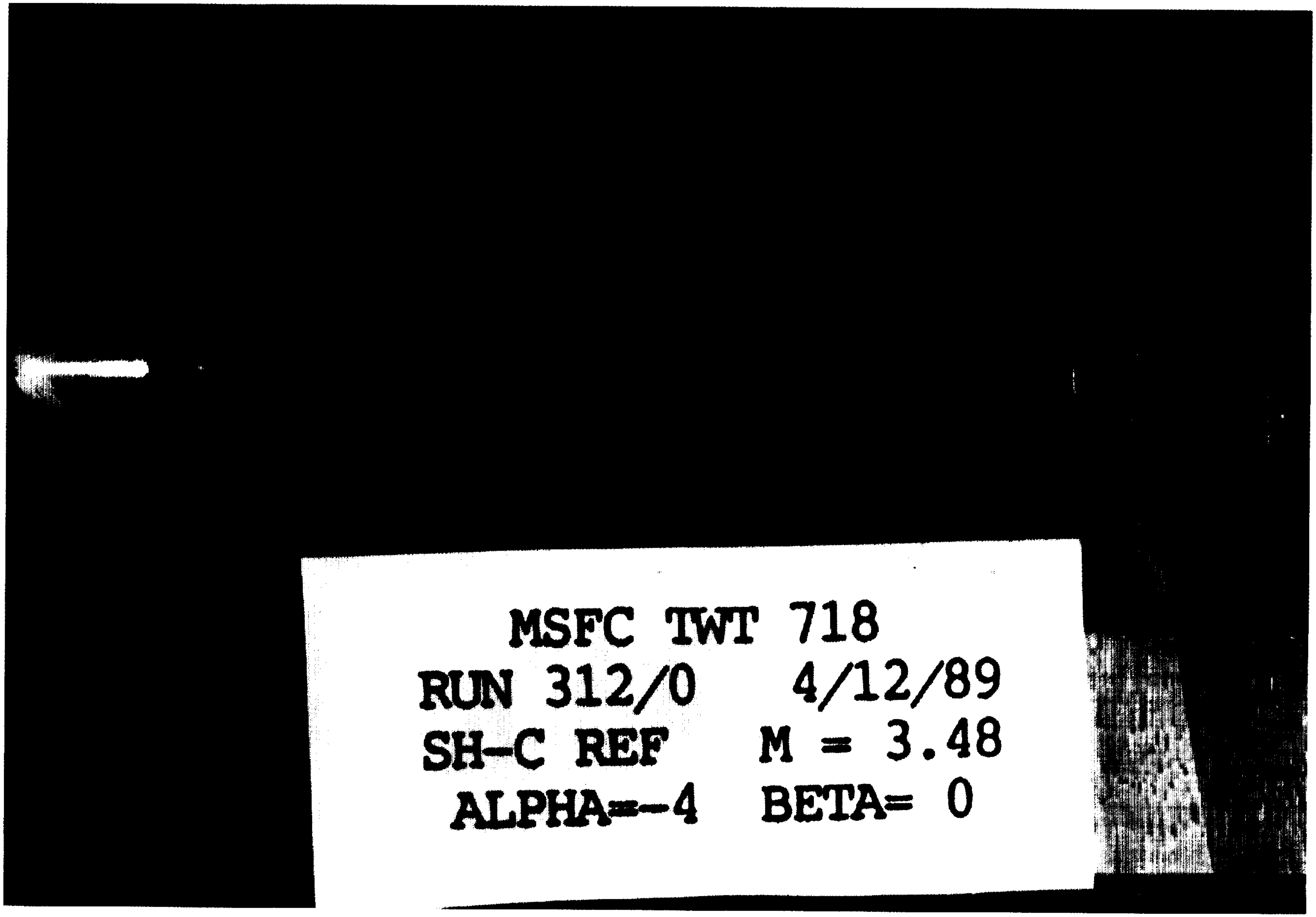


Figure 72. Shuttle-C cargo carrier Mach 3.48, alpha = -4, beta = 0, phi = 90.

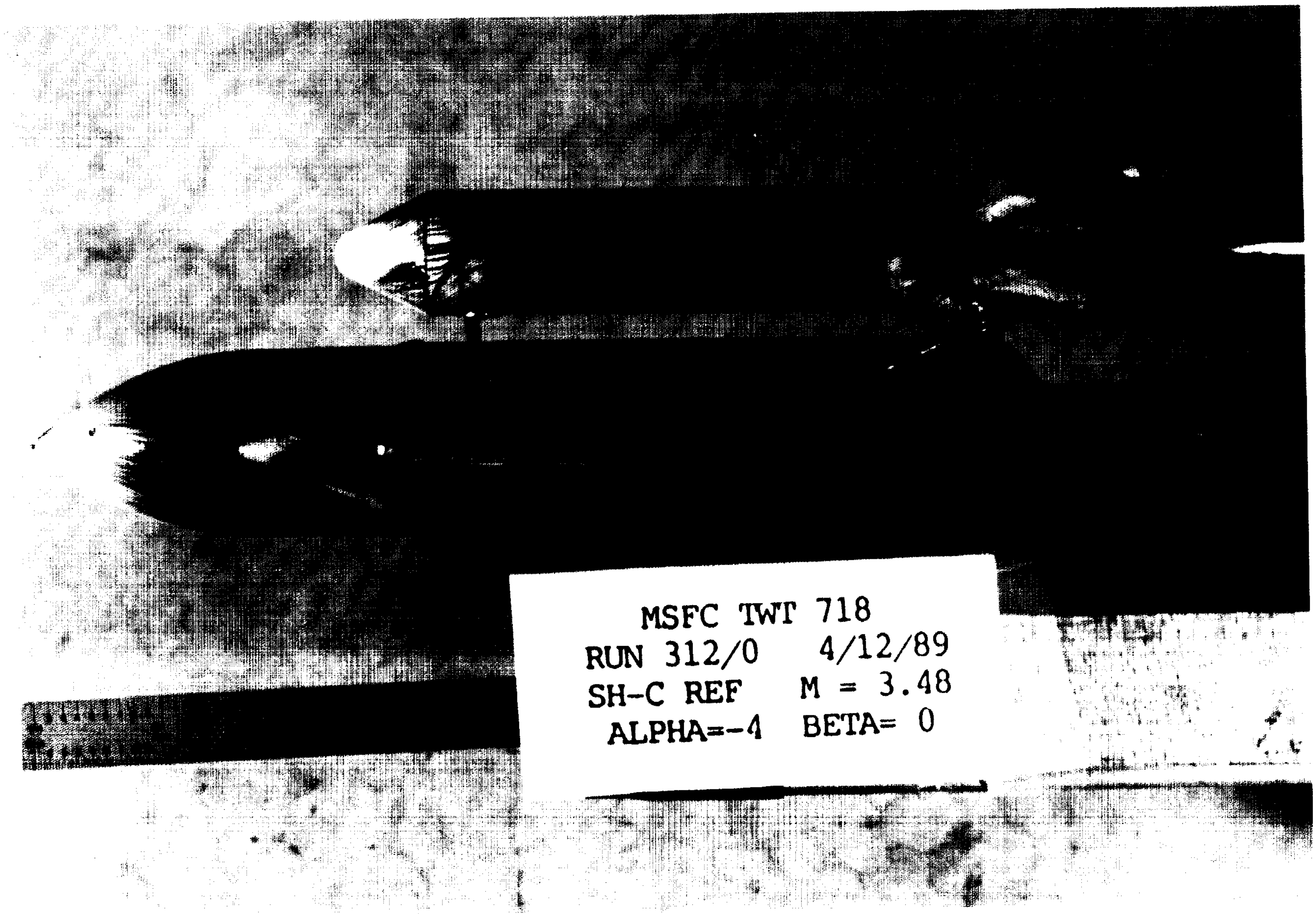


Figure 73. Shuttle-C mated vehicle Mach 3.48, alpha = -4, beta = 0, phi = 0.

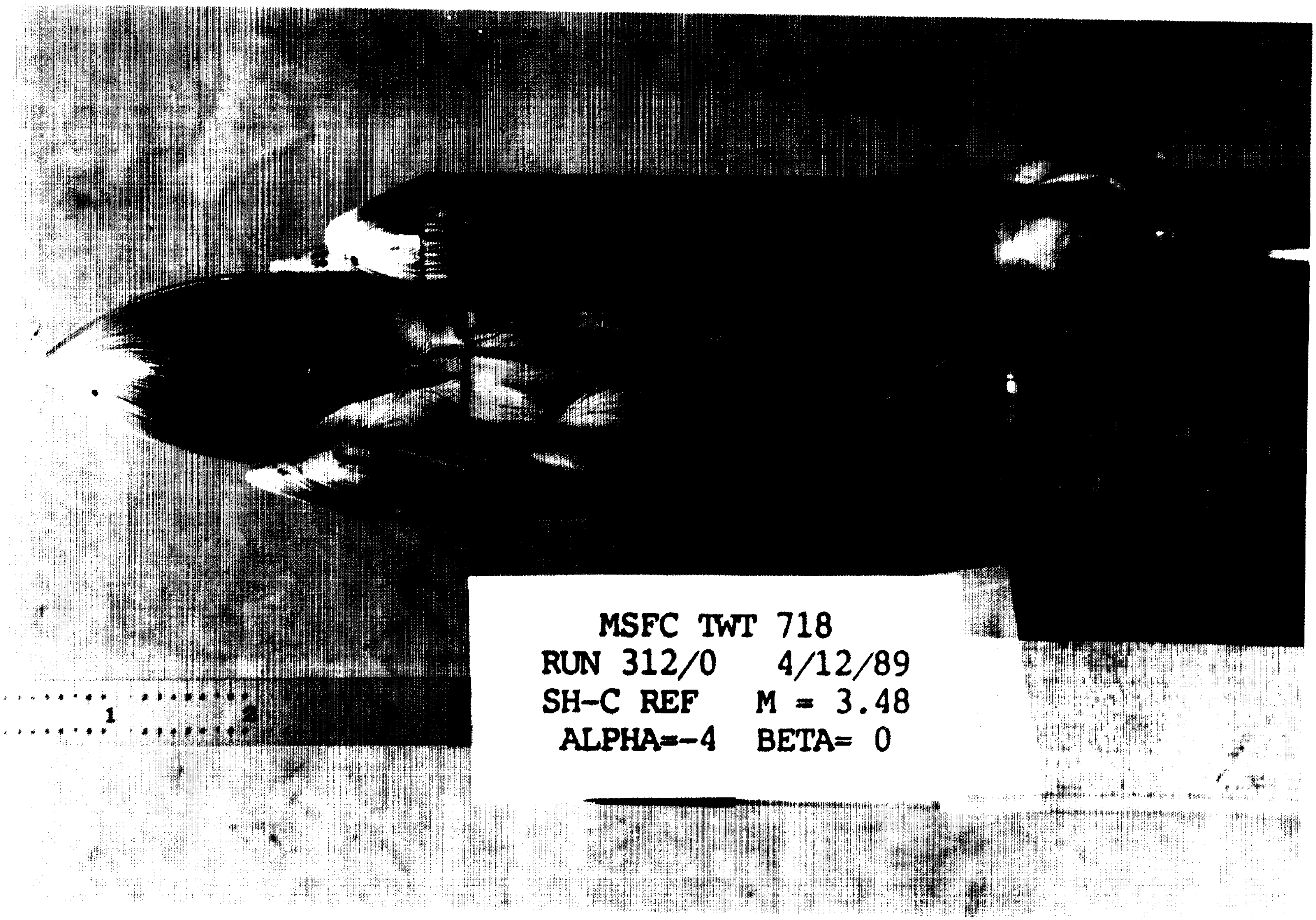


Figure 74. Shuttle-C mated vehicle Mach 3.48, alpha = -4, beta = 0, phi = 45.

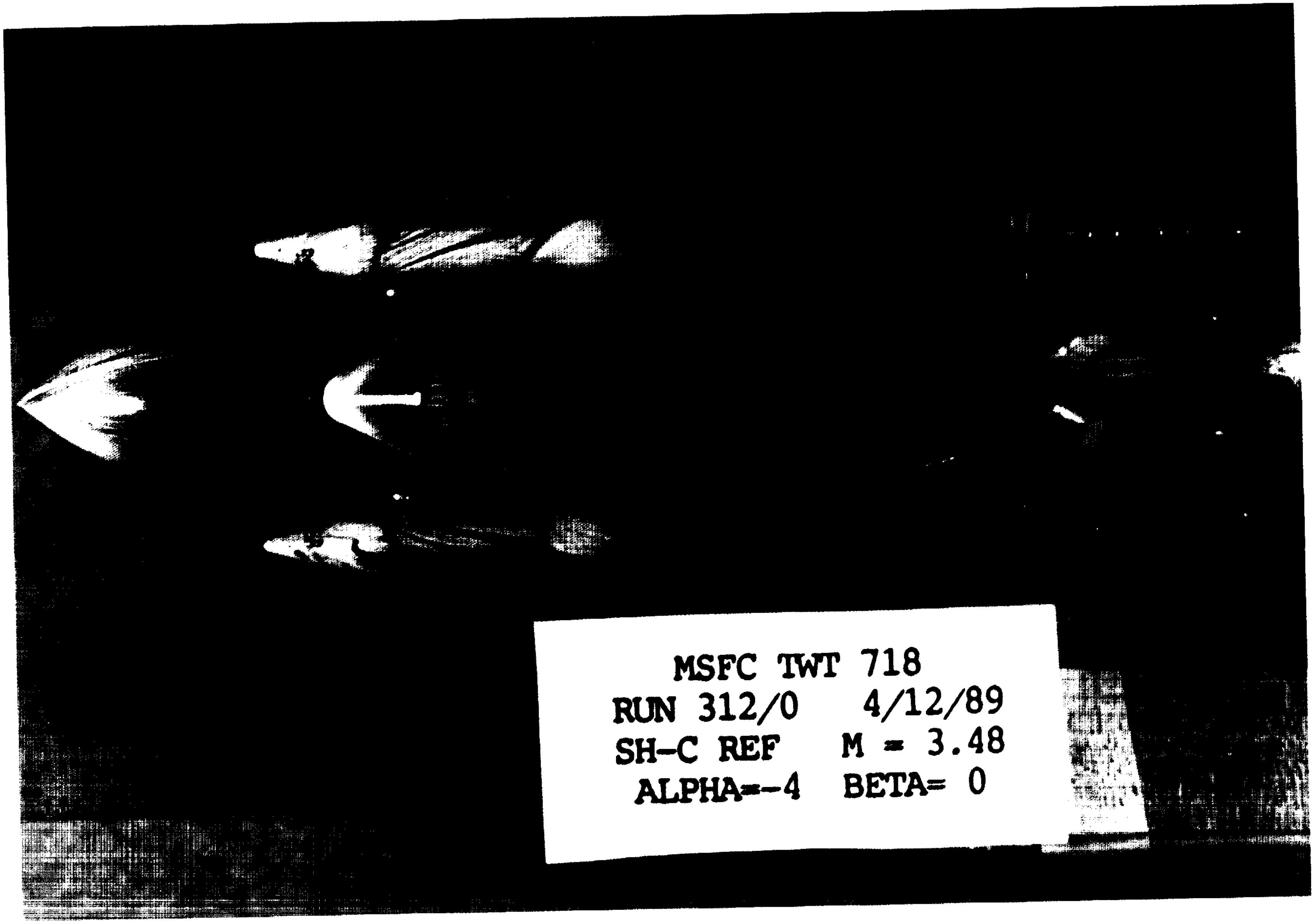


Figure 75. Shuttle-C mated vehicle Mach 3.48, alpha = -4, beta = 0, phi = 90.

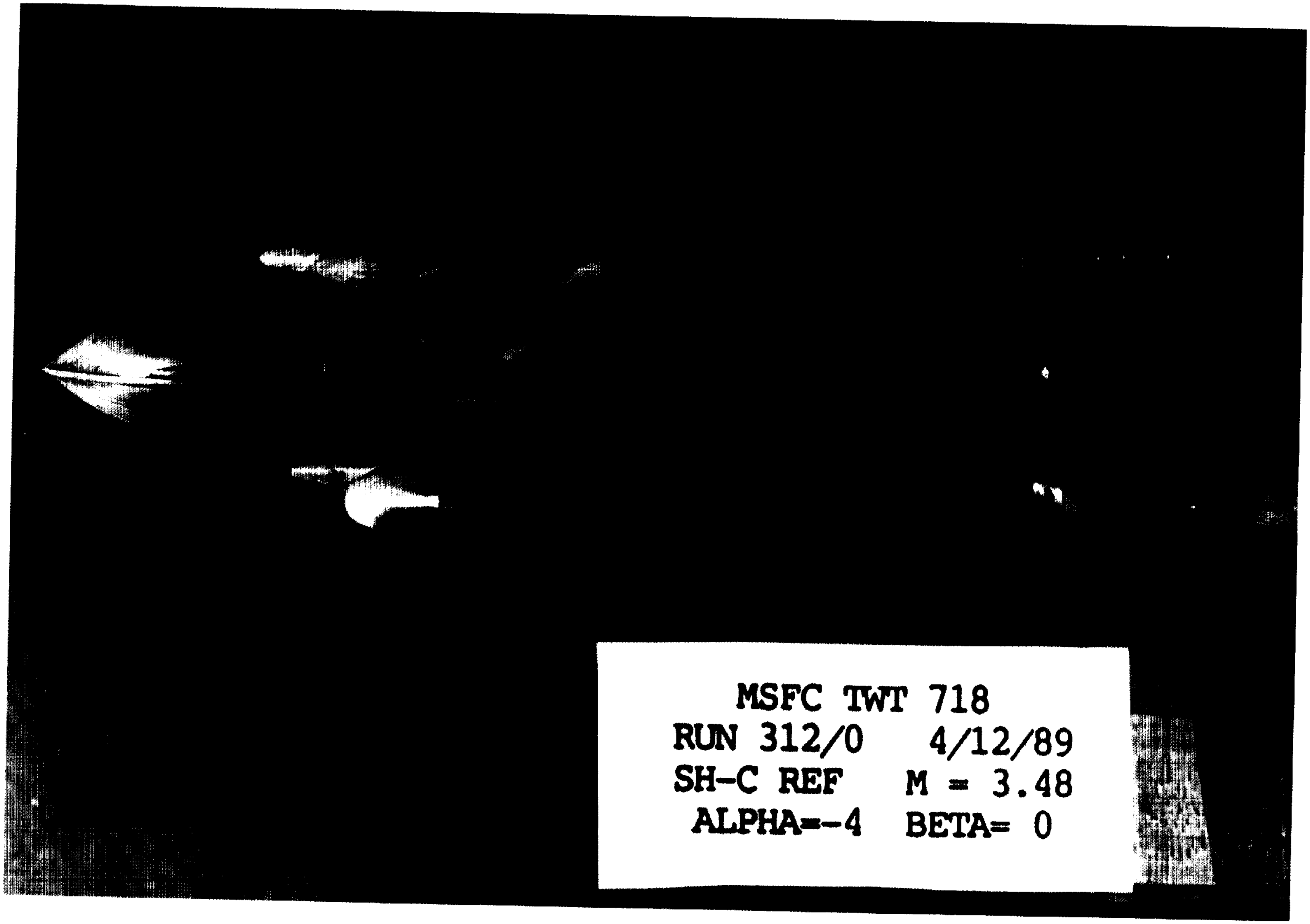


Figure 76. Shuttle-C mated vehicle Mach 3.48, alpha = -4, beta = 0, phi = 135.

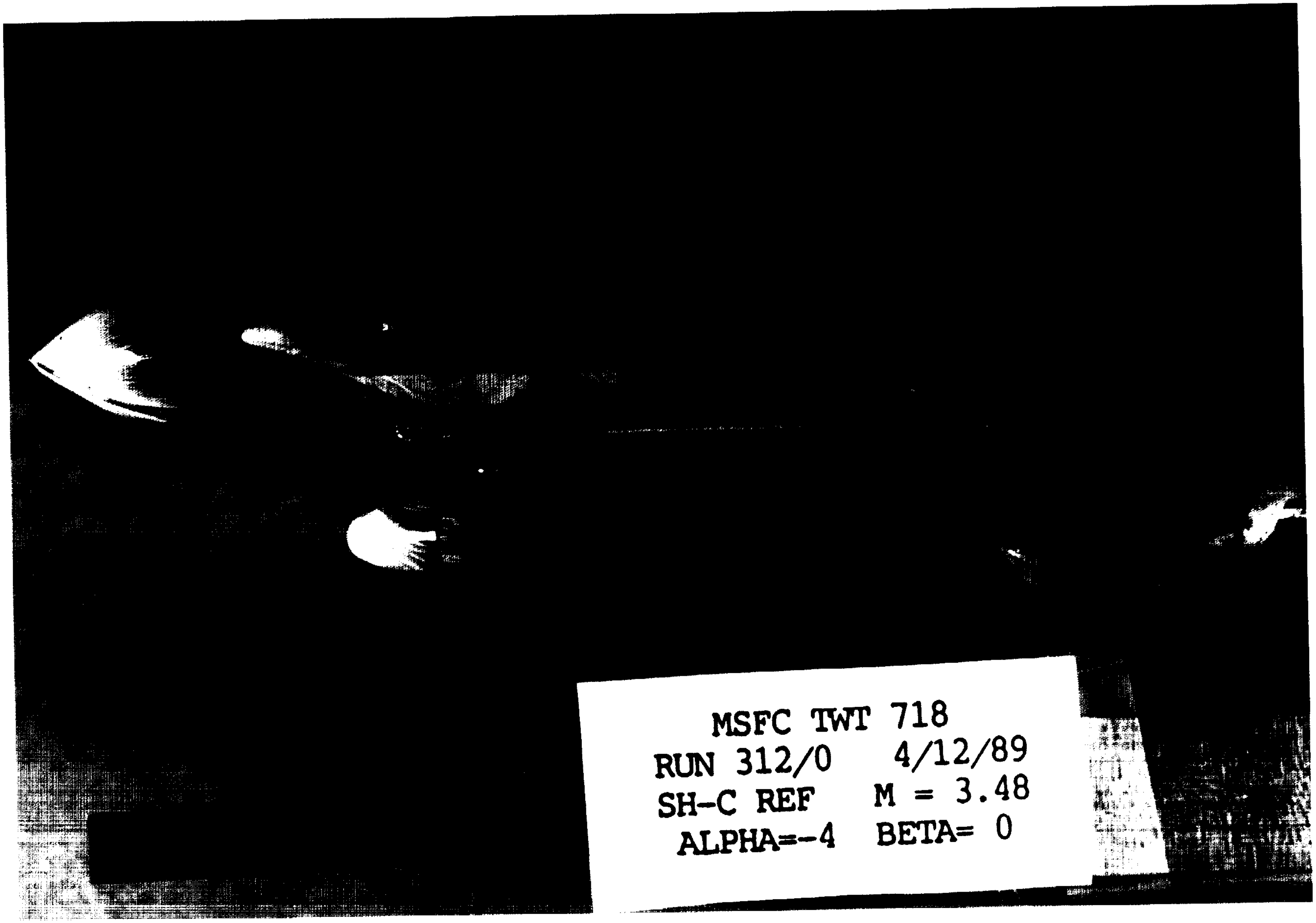


Figure 77. Shuttle-C mated vehicle Mach 3.48, alpha = -4, beta = 0, phi = 180.

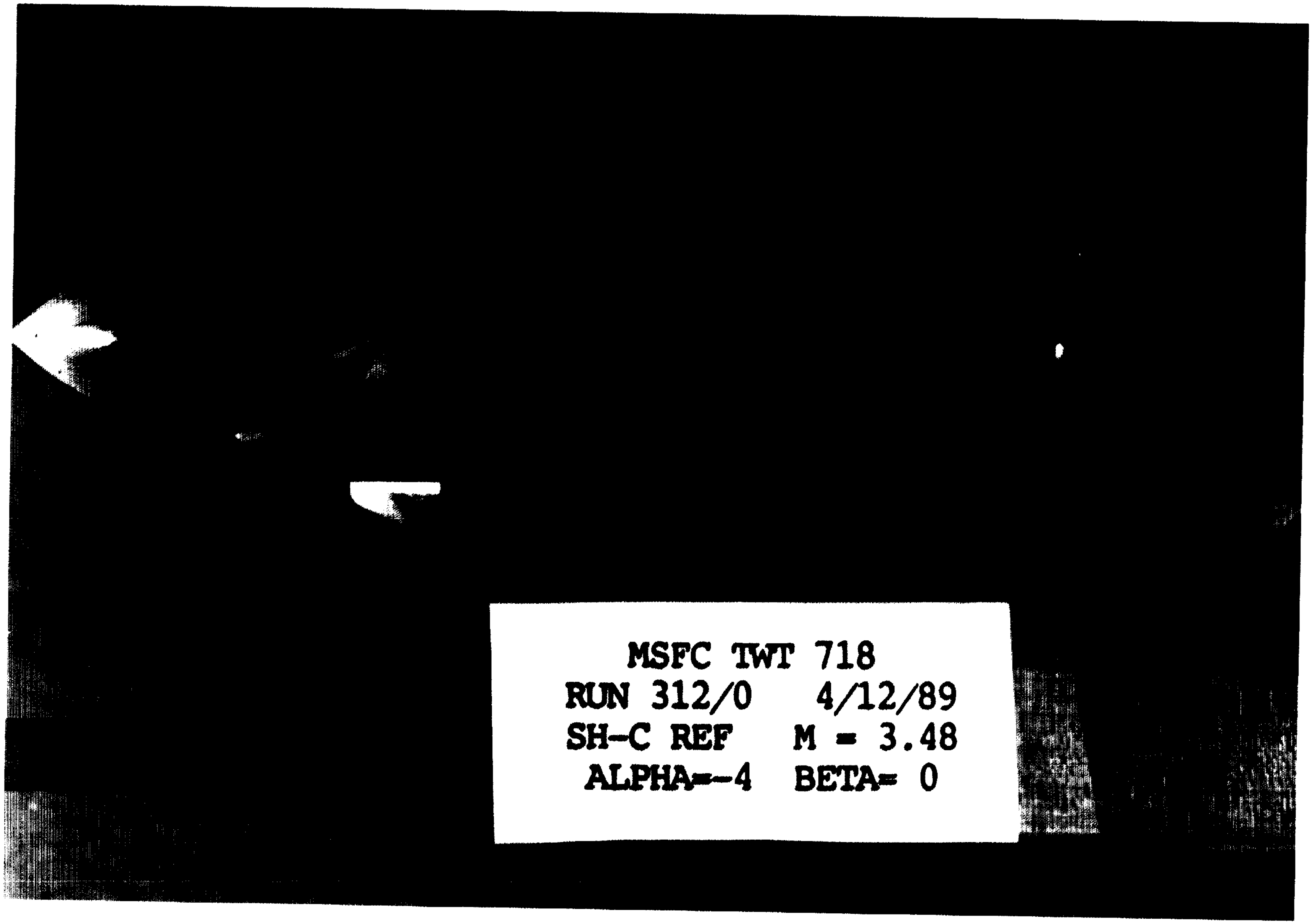


Figure 78. Shuttle-C mated vehicle Mach 3.48, alpha = -4, beta = 0, phi = 225.

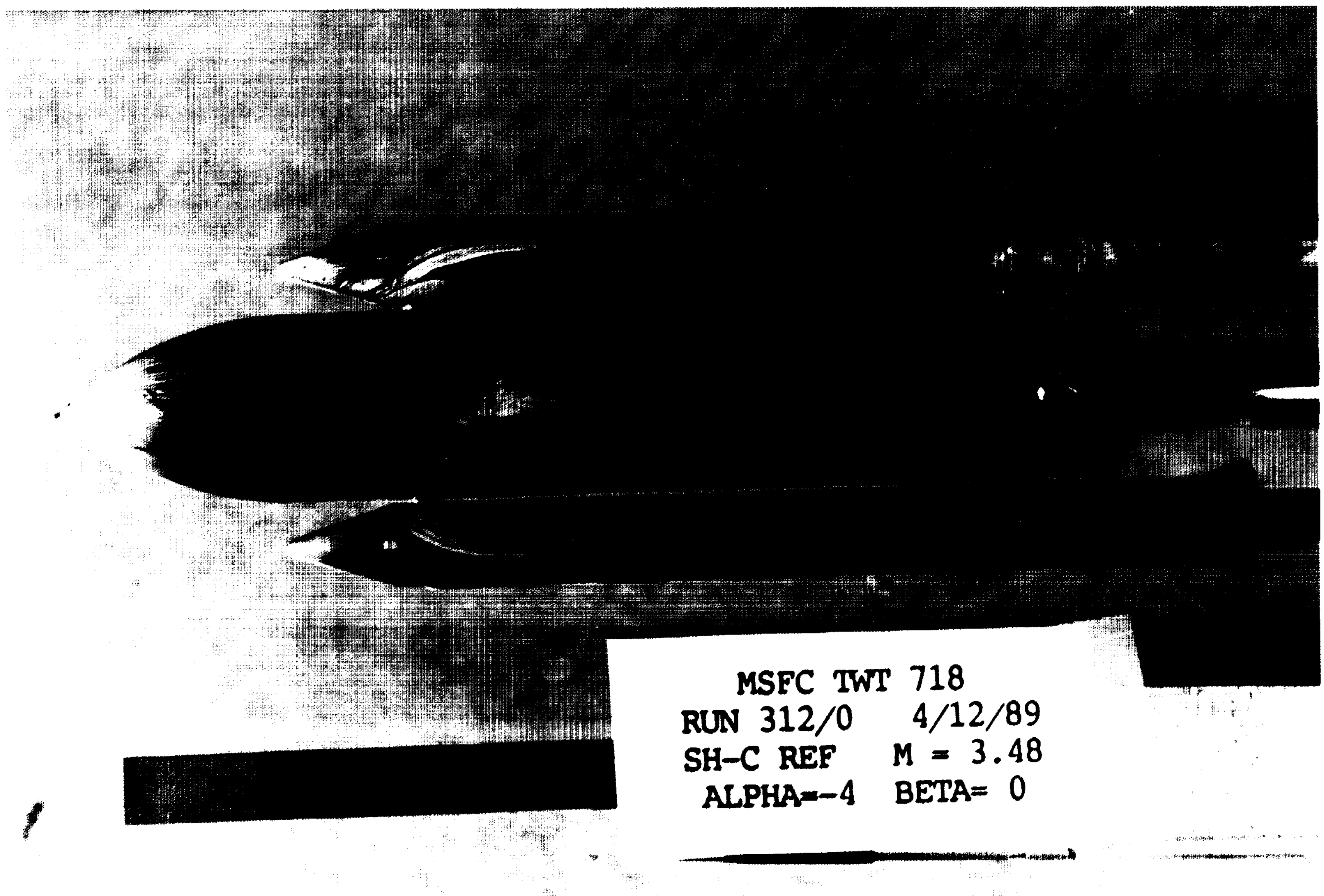


Figure 79. Shuttle-C mated vehicle Mach 3.48, alpha = -4, beta = 0, phi = 270.

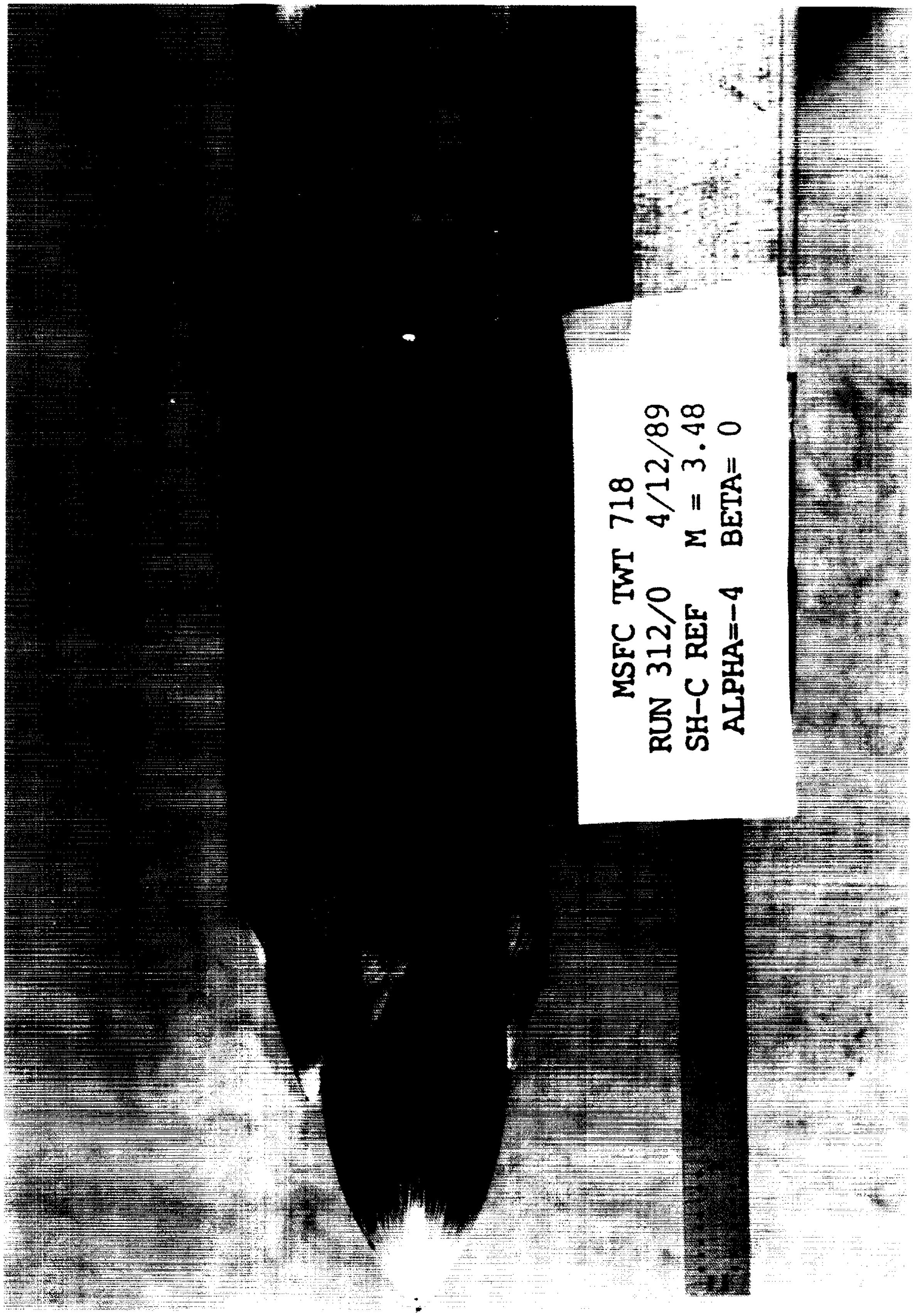


Figure 80. Shuttle-C mated vehicle Mach 3.48, alpha = -4, beta = 0, phi = 315.



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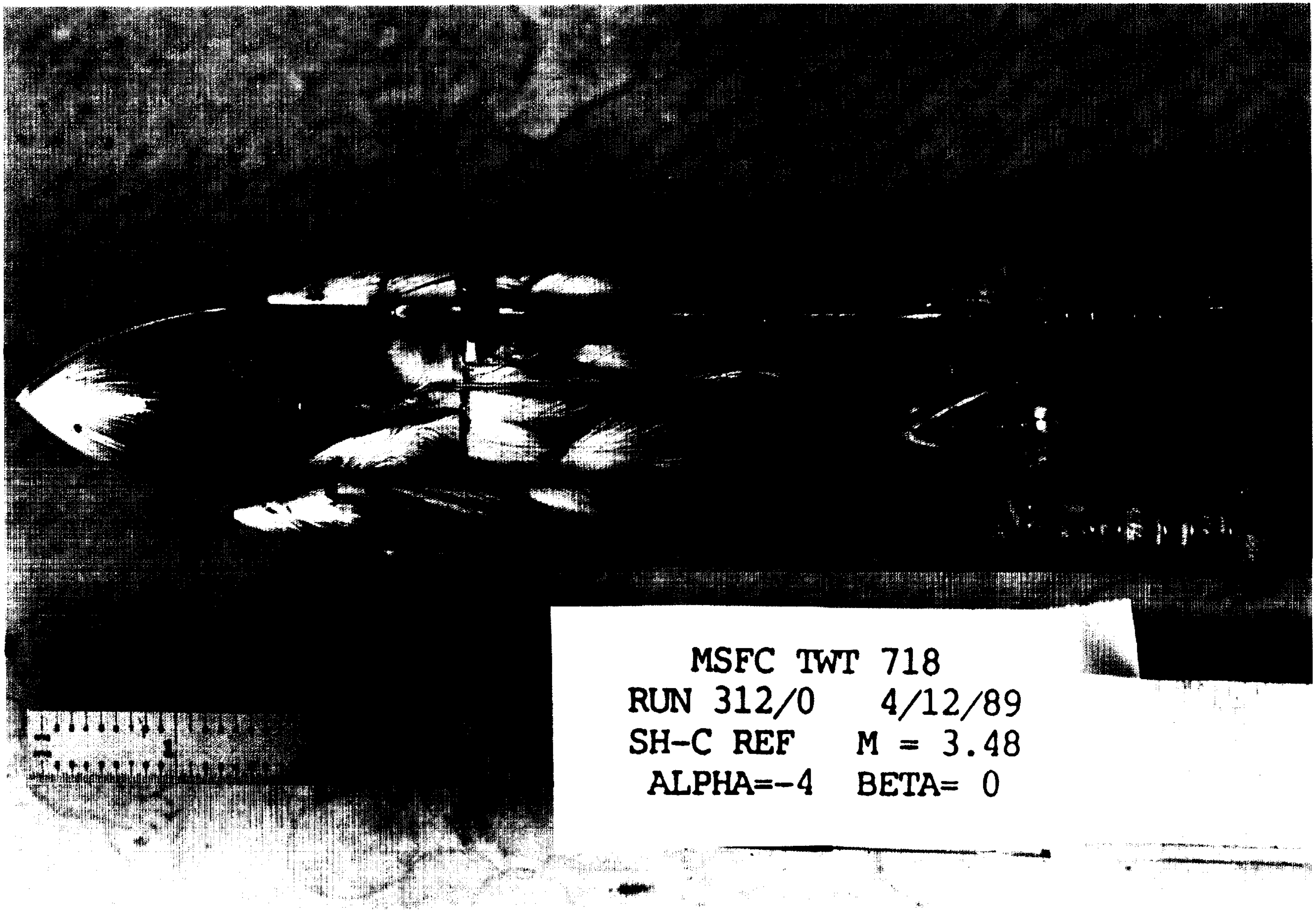


Figure 81. Shuttle-C lower stack Mach 3.48, alpha = -4, beta = 0, phi = 0.

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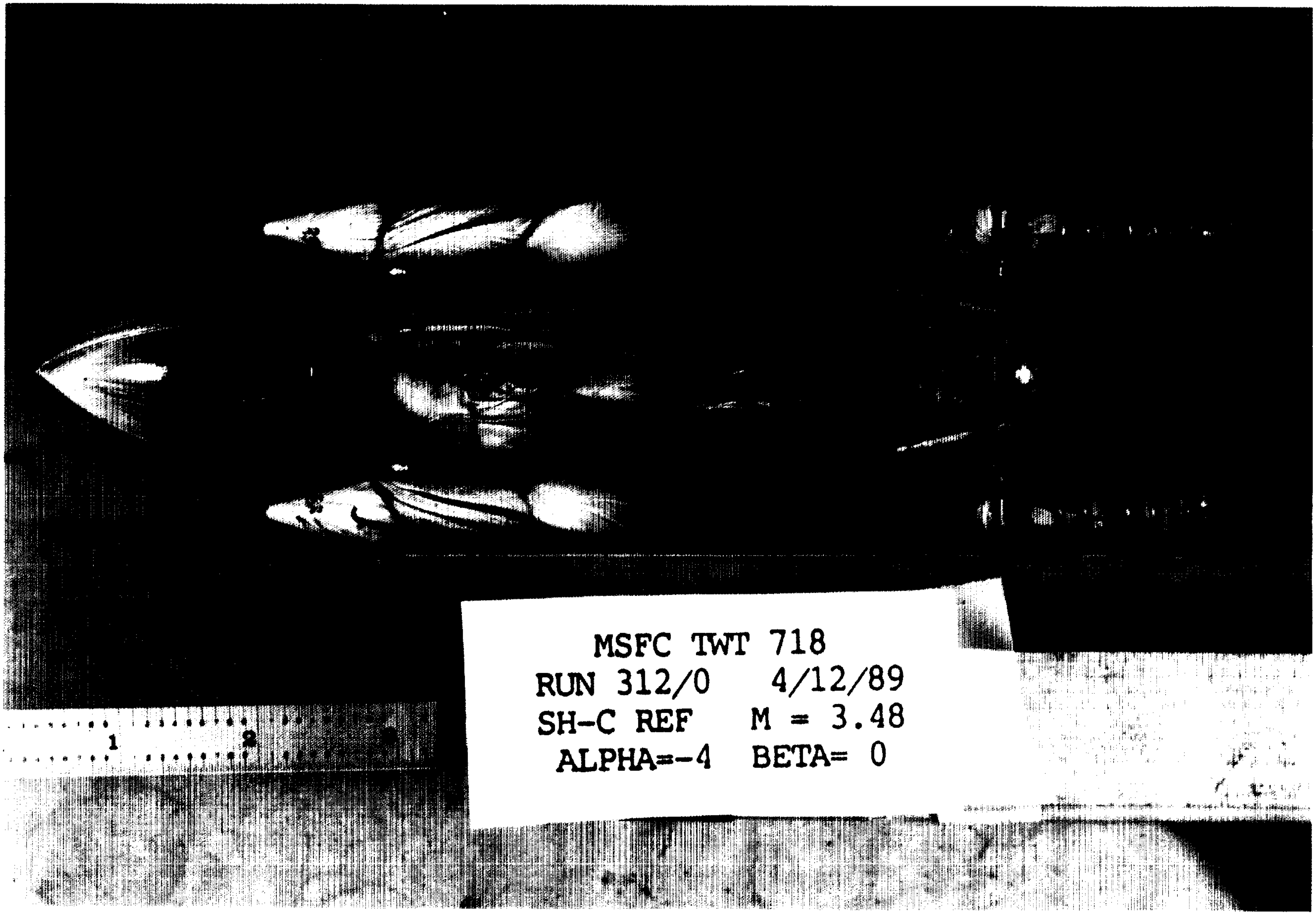


Figure 82. Shuttle-C lower stack Mach 3.48, alpha = -4, beta = 0, phi = 45.

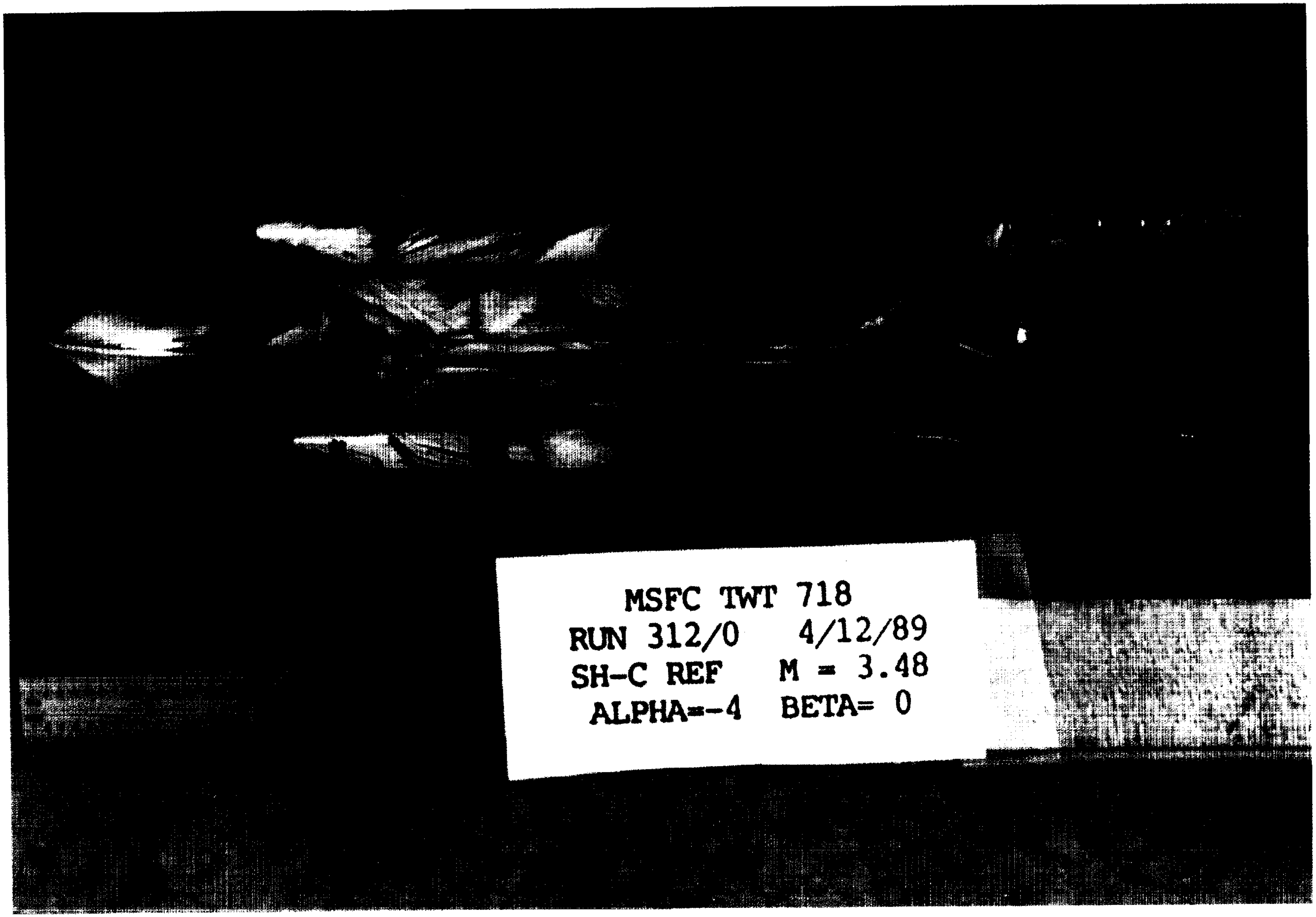


Figure 83. Shuttle-C lower stack Mach 3.48, alpha = -4, beta = 0, phi = 90.

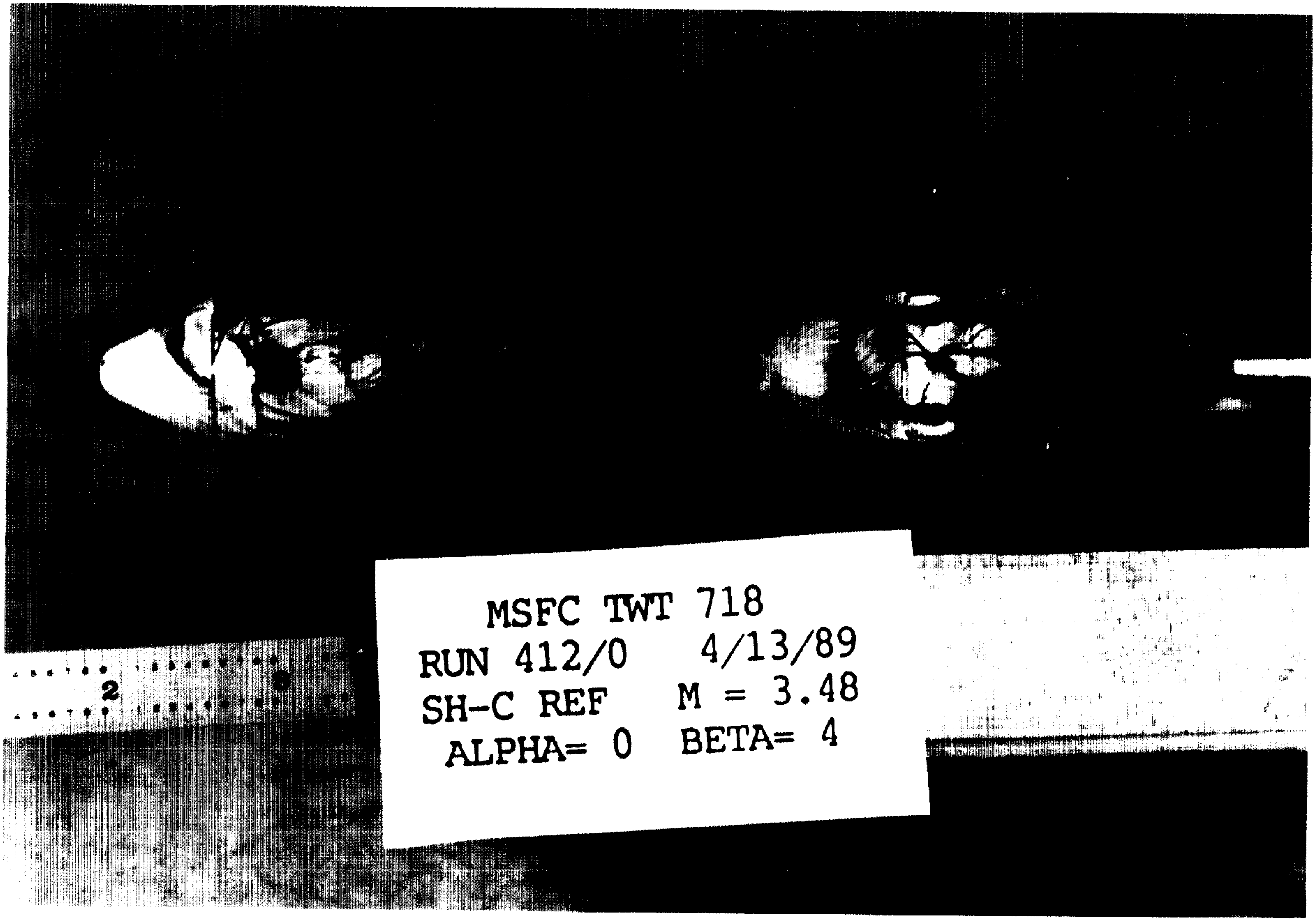


Figure 84. Shuttle-C cargo carrier Mach 3.48, alpha = 0, beta = 4, phi = 90.



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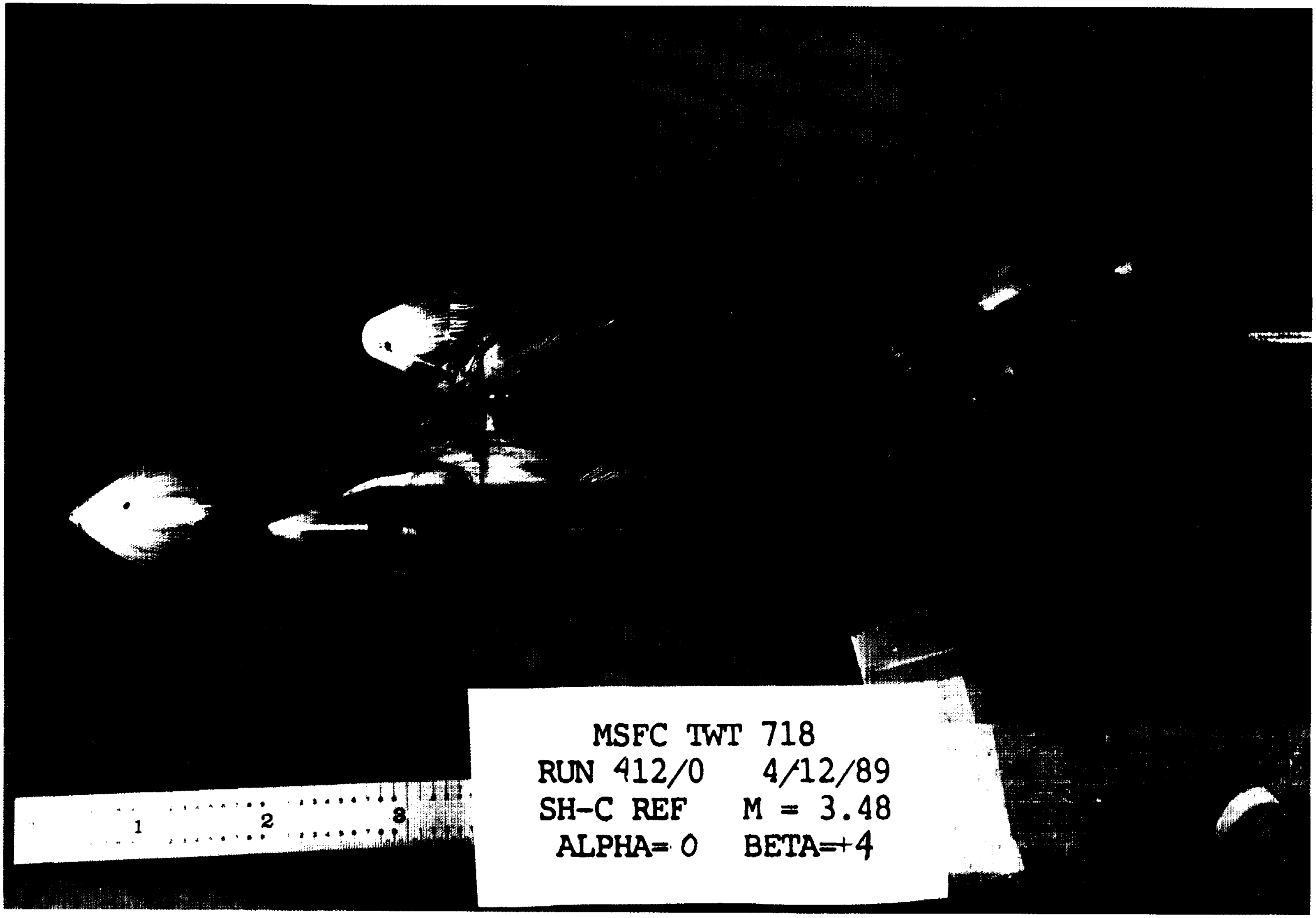


Figure 85. Shuttle-C mated vehicle Mach 3.48, alpha = 0, beta = 4, phi = 0.

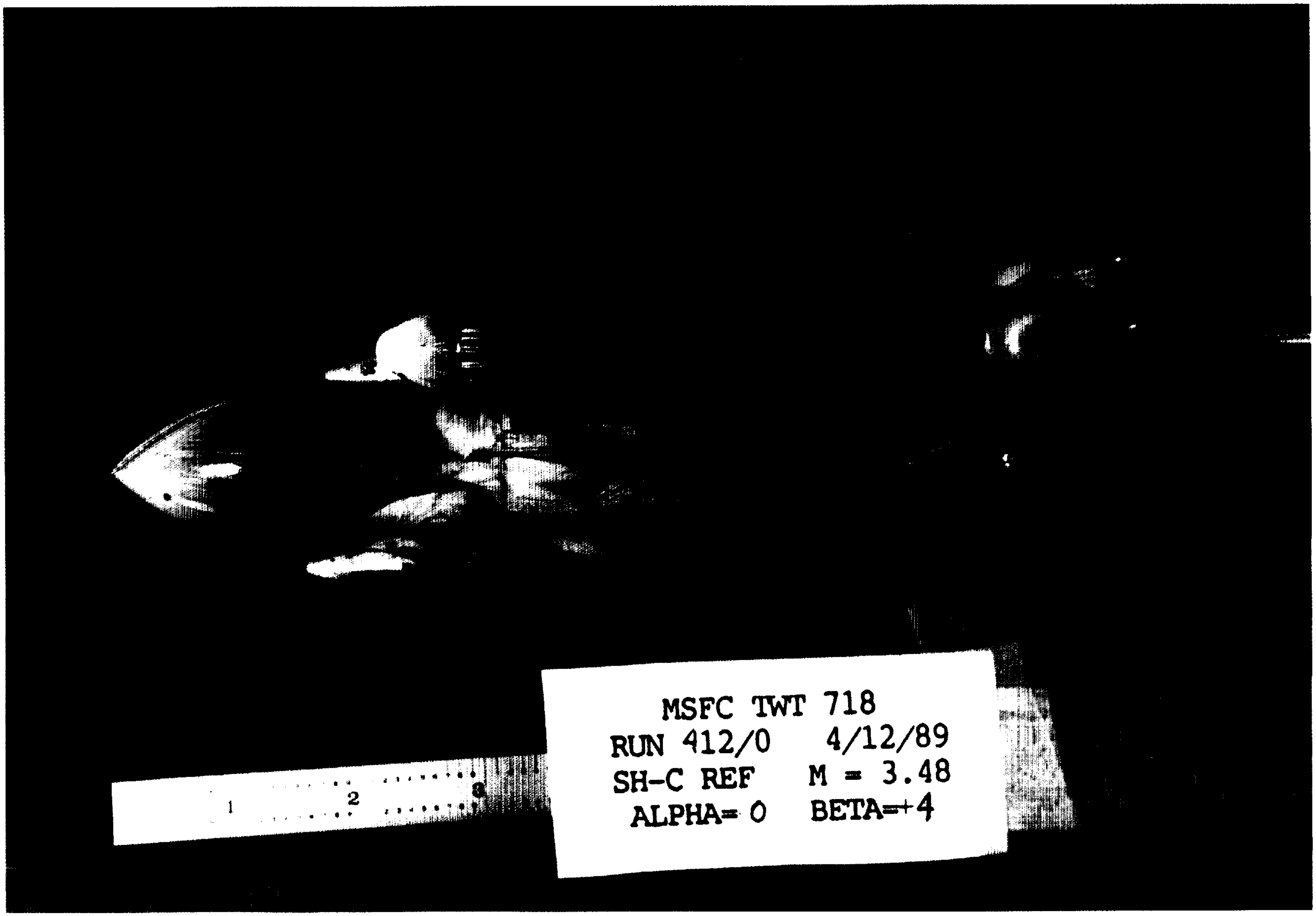


Figure 86. Shuttle-C mated vehicle Mach 3.48, alpha = 0, beta = 4, phi = 45.

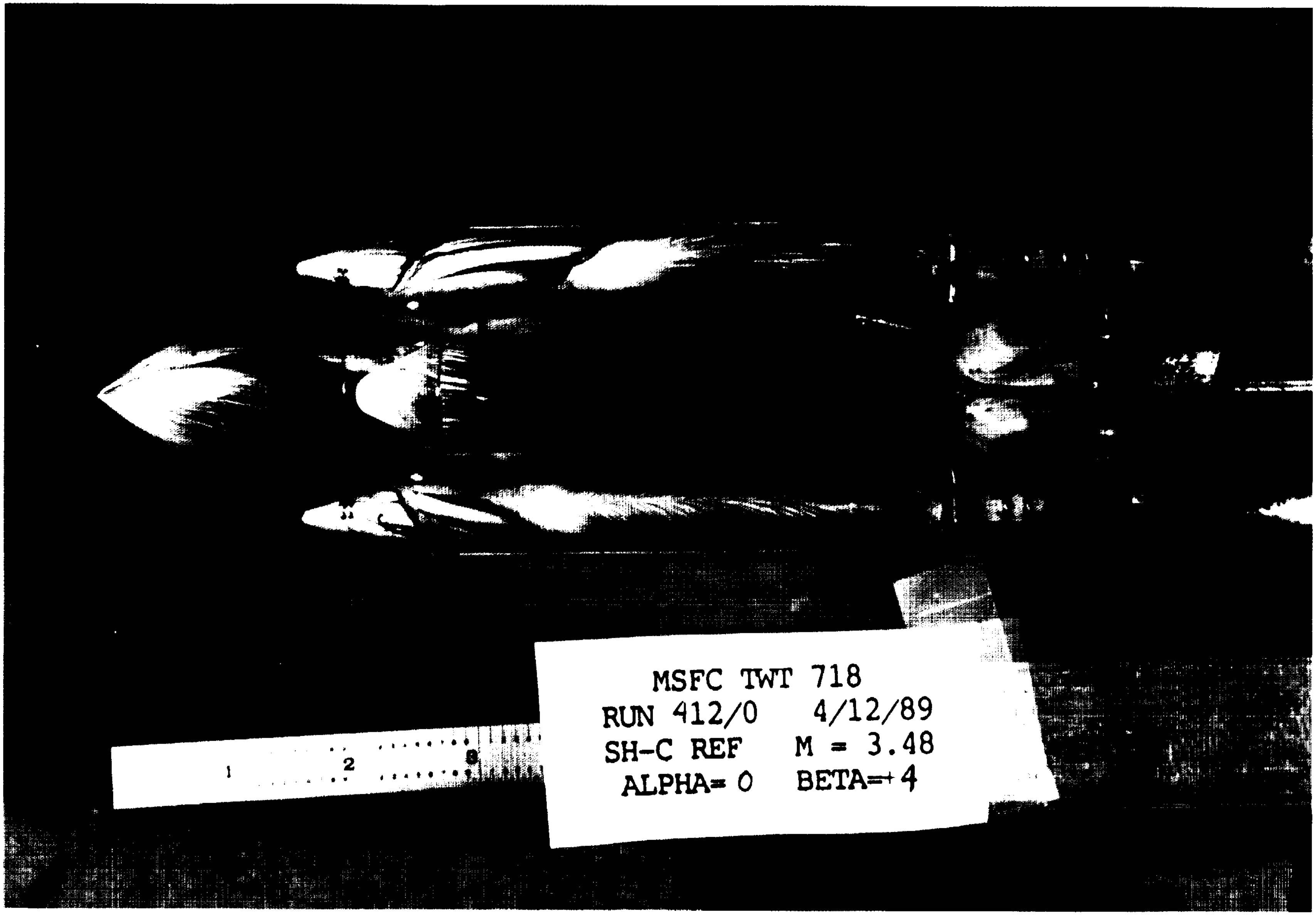


Figure 87. Shuttle-C mated vehicle Mach 3.48, alpha = 0, beta = 4, phi = 90.

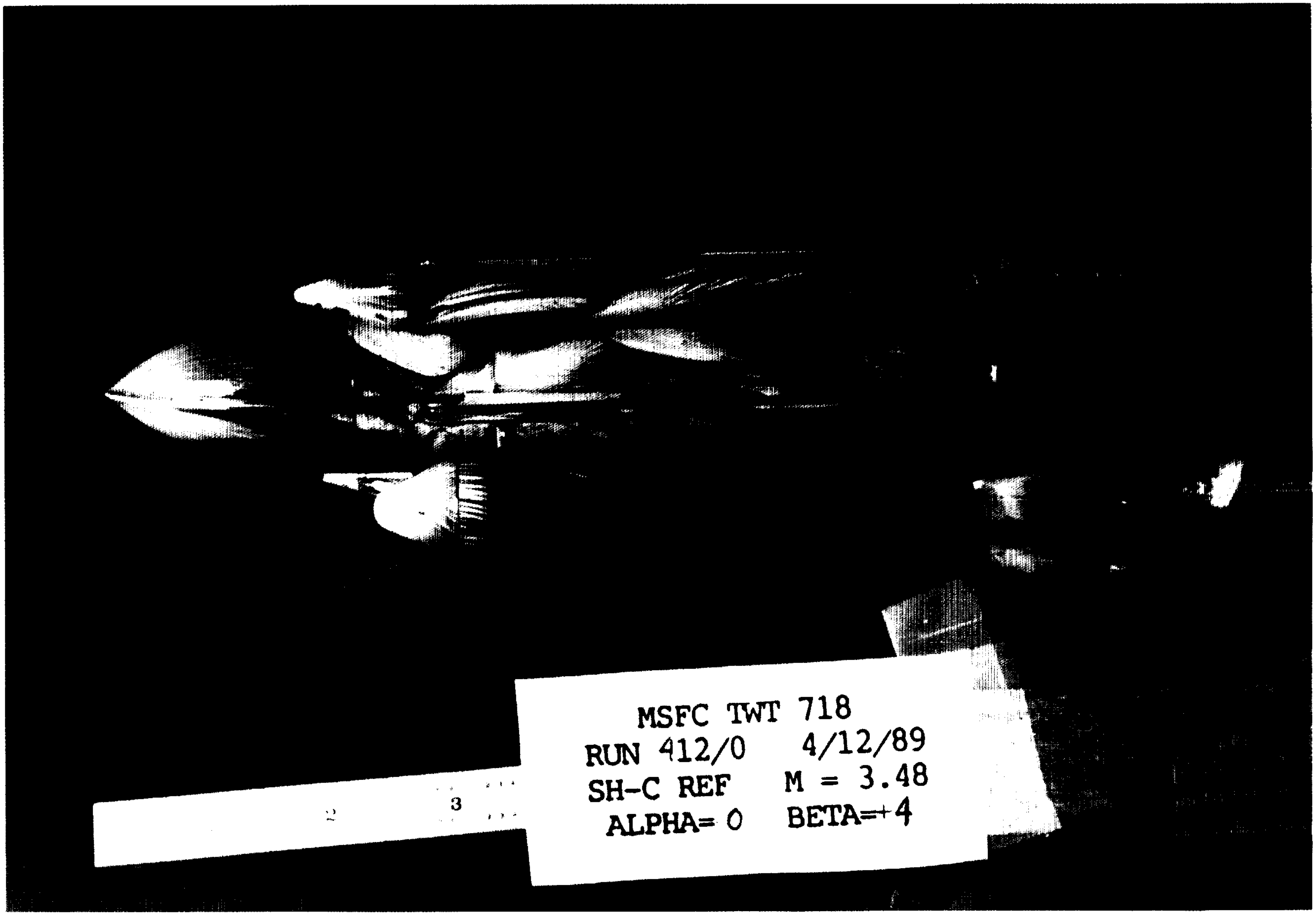


Figure 88. Shuttle-C mated vehicle Mach 3.48, alpha = 0, beta = 4, phi = 135.

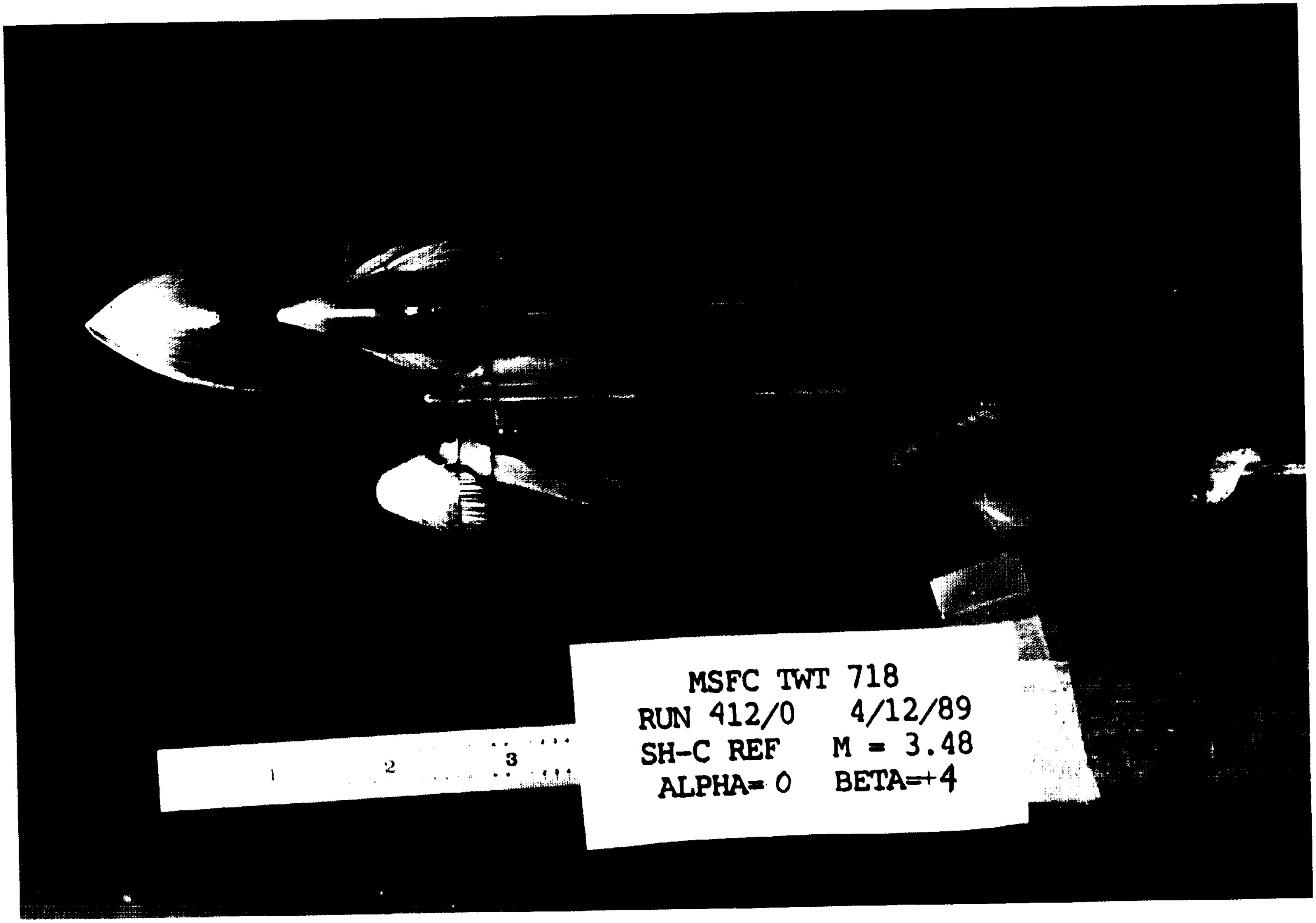


Figure 89. Shuttle-C mated vehicle Mach 3.48, alpha = 0, beta = 4, phi = 180.

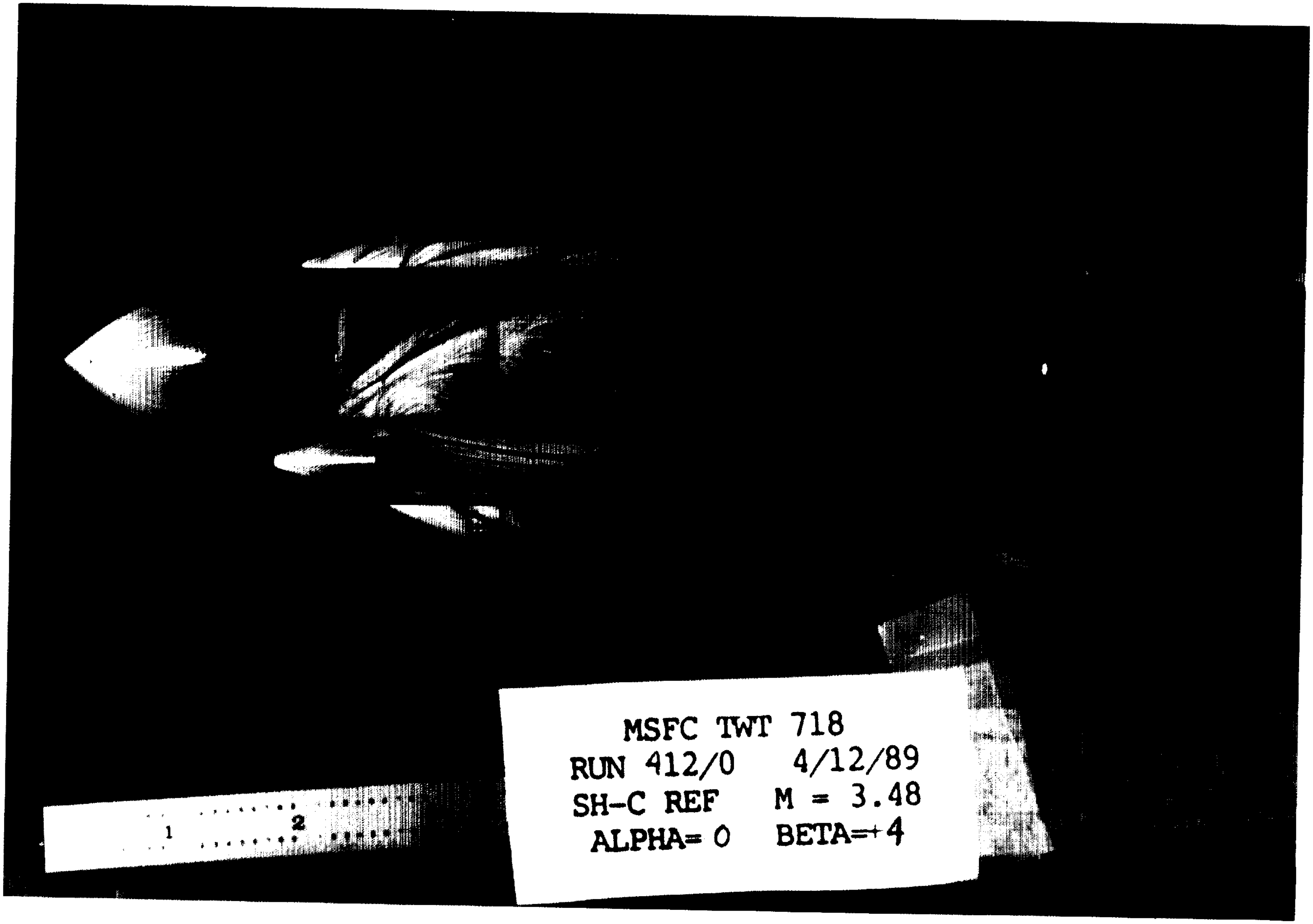


Figure 90. Shuttle-C mated vehicle Mach 3.48, alpha = 0, beta = 4, phi = 225.

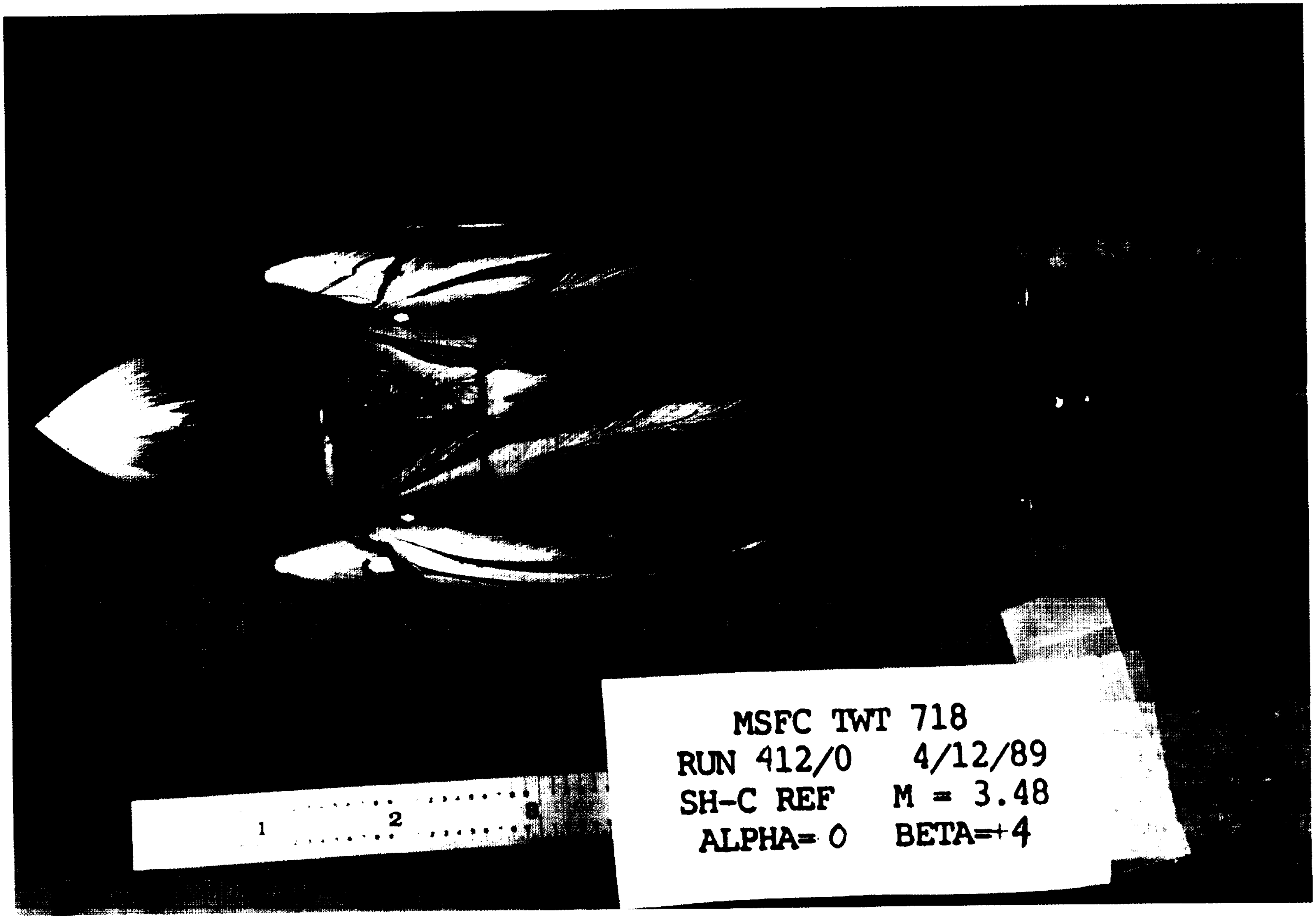


Figure 91. Shuttle-C mated vehicle Mach 3.48, alpha = 0, beta = 4, phi = 270.

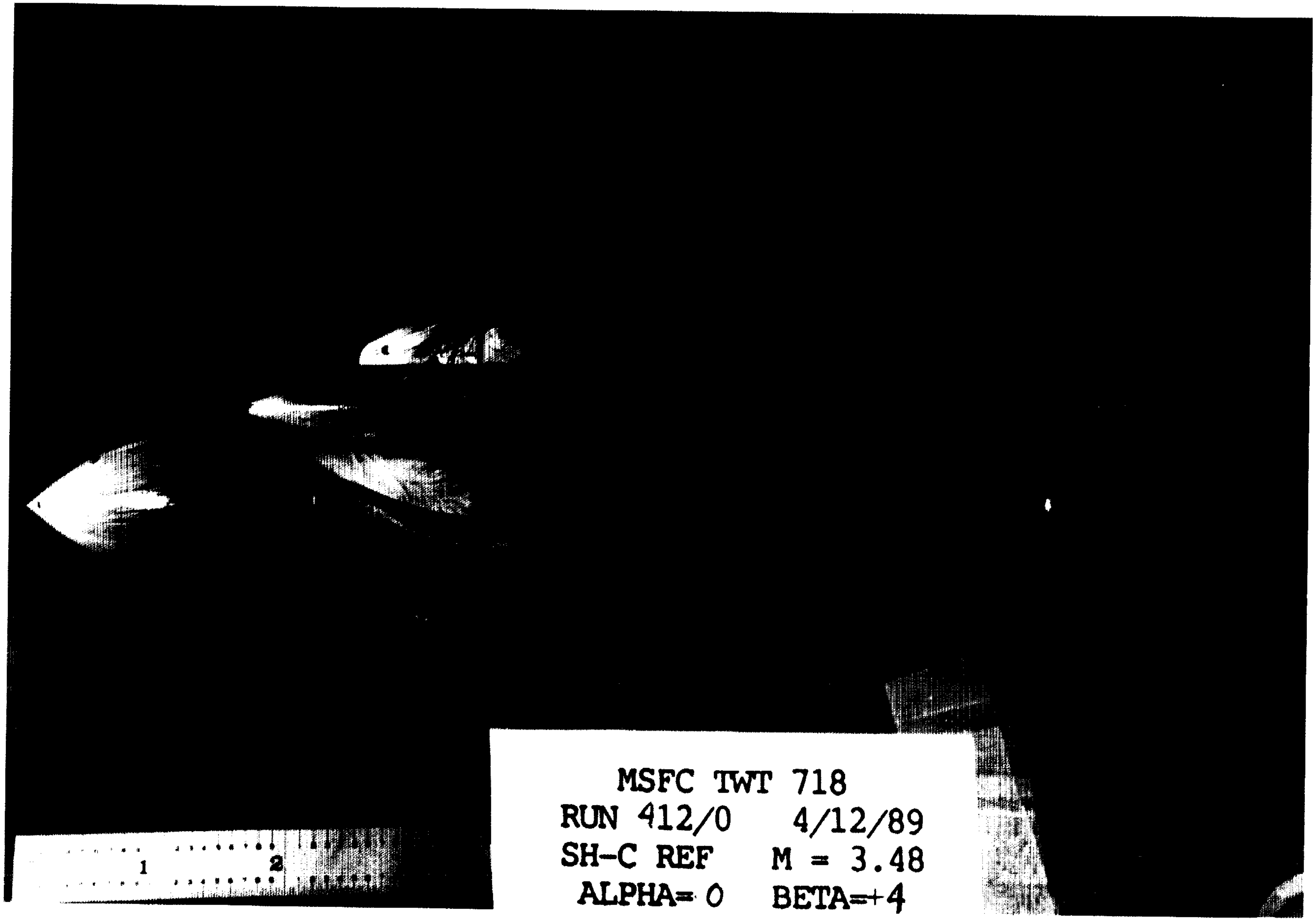


Figure 92. Shuttle-C mated vehicle Mach 3.48, alpha = 0, beta = 4, phi = 315.

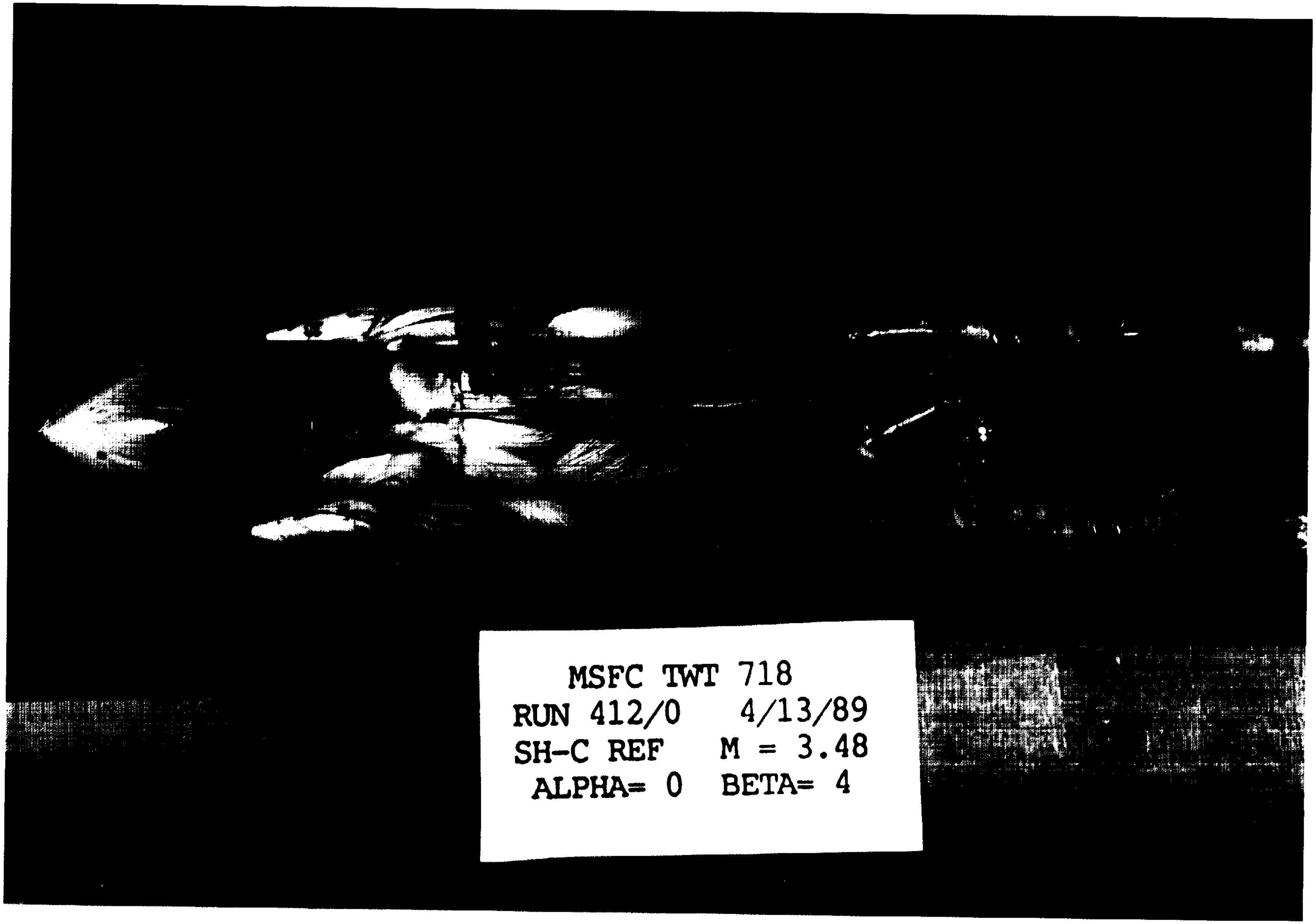


Figure 93. Shuttle-C lower stack Mach 3.48, alpha = 0, beta = 4, phi = 0.

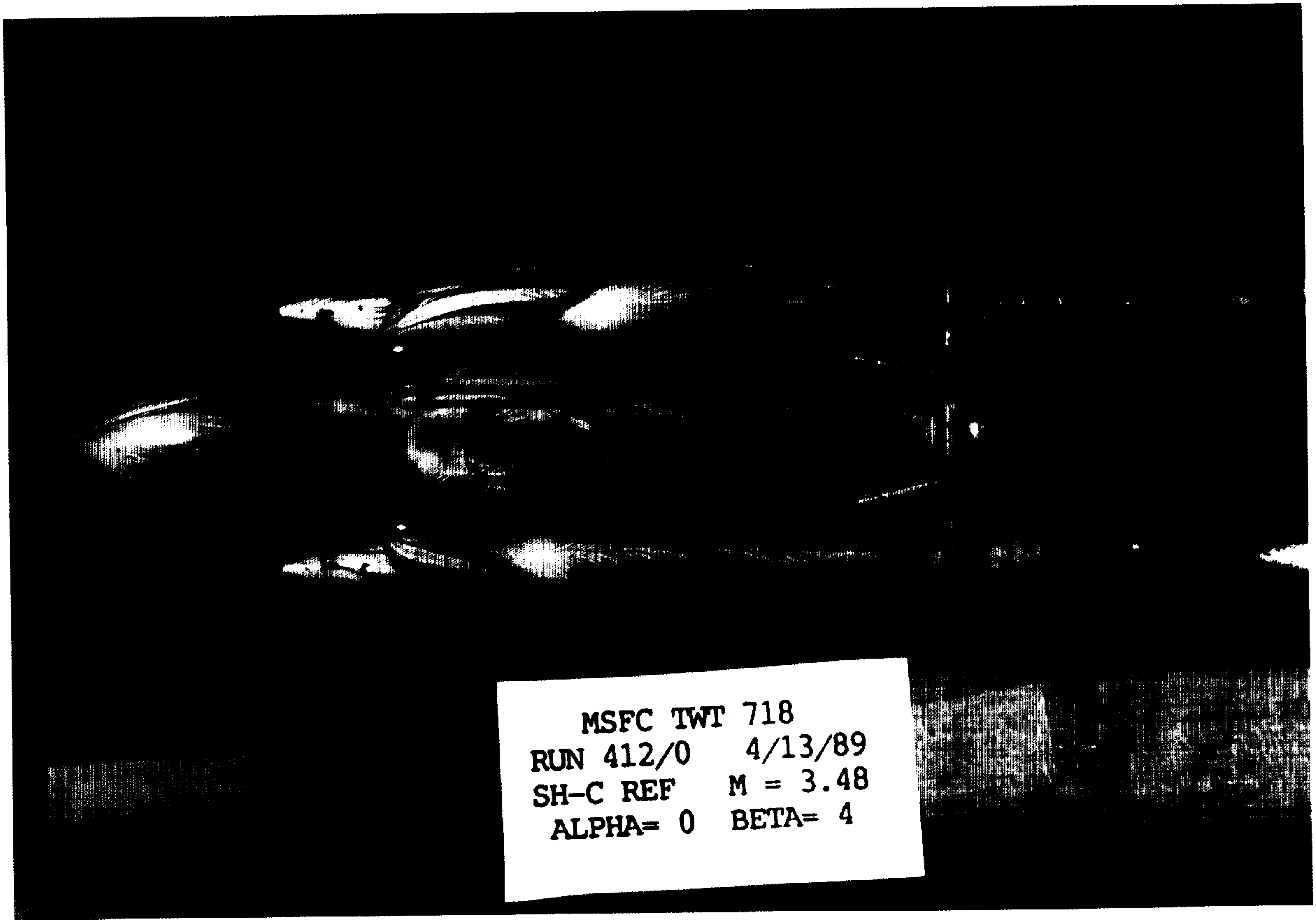


Figure 94. Shuttle-C lower stack Mach 3.48, alpha = 0, beta = 4, phi = 45.

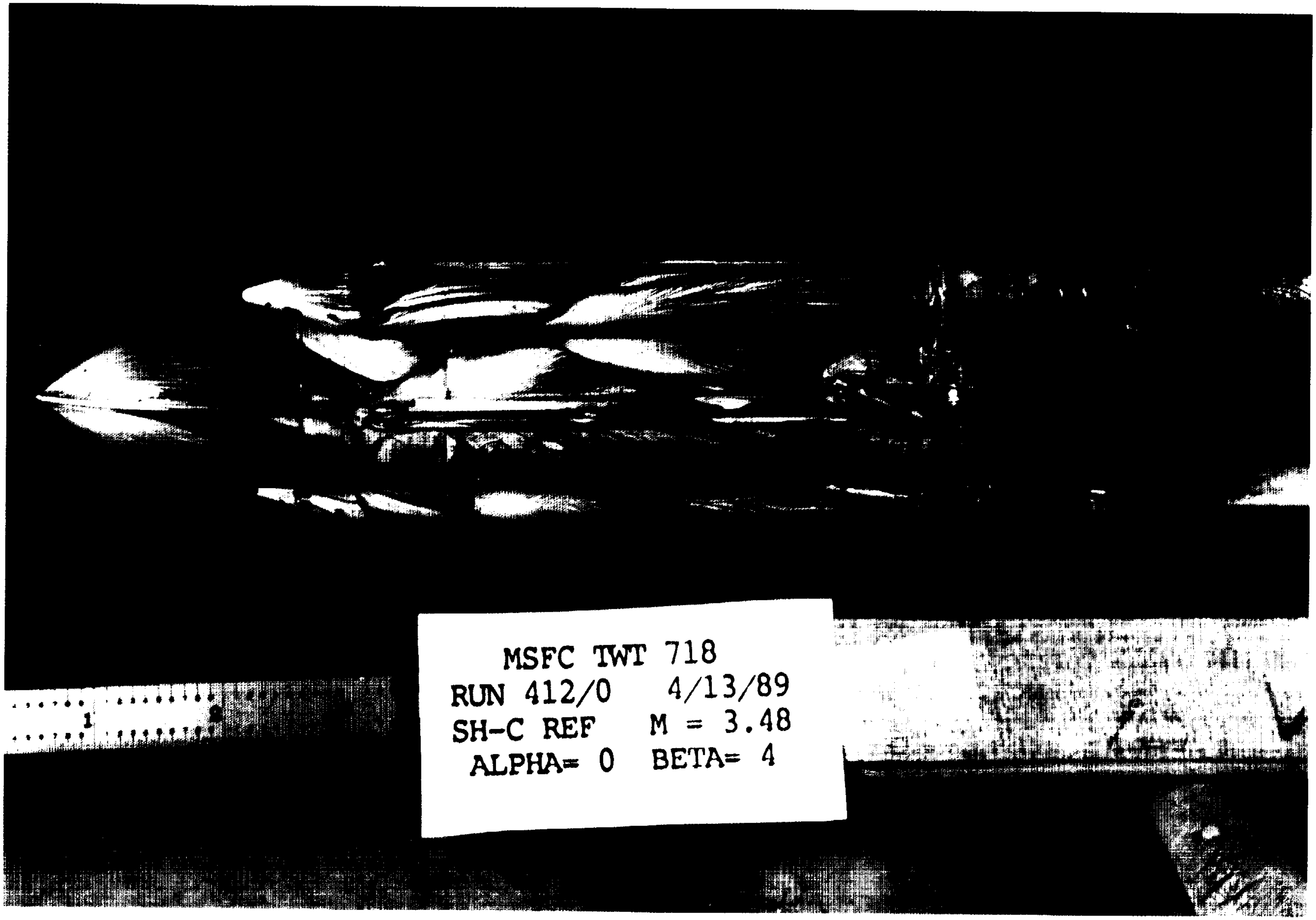


Figure 95. Shuttle-C lower stack Mach 3.48, alpha = 0, beta = 4, phi = 90.

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**13. ABSTRACT** *(Maximum 200 words)*

An oil flow study of the reference Shuttle-C configuration is presented. The Shuttle-C vehicle was a proposed shuttle derived vehicle where the orbiter was to be replaced by an unmanned cargo carrier element. Oil flows are shown for the range of Mach numbers from Mach 1.10 to 3.48 at various angles-of-attack and roll angles. The major flow field phenomena over the Shuttle-C reference configuration are shown in these oil flows. Using the oil flows, a qualitative understanding of the flow around the vehicle can be determined, aiding the quantitative definition of aerodynamic data from theoretical analyses and test results. The oil flows presented in this study were obtained from configurations tested in the NASA Marshall Space Flight Center's 14-Inch Trisonic Wind Tunnel from October 1988 through February 1989.

**14. SUBJECT TERMS**
flow visualization, launch vehicle, oil flow, Shuttle-C, shuttle derived vehicle, wind tunnel testing

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