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IMPROVEMENT OF AIRCRAFT WINDSHIELD SYSTEM BIRDSTRIKE RESISTANCE*

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ABSTRACT

USAF aircraft repeatedly prove that birds and aircraft cannot occupy the same airspace at the same time; over 1000 birdstrikes per year cause millions of dollar in damage to USAF aircraft. During the past fifteen years eleven military pilots have been killed and eighteen aircraft have been destroyed due to bird impact. Mo of these losses are due to birdstrikes on the windshield subsystem than to any oth subsystem. Windshield systems on several different aircraft are being evaluated to their birdstrike resistance and/or are being redesigned to provide improved tolerance of the birdstrike event. These analytical and experimental efforts to define and improve windshield system birdstrike resistance are reviewed in general terms. Some technical voids in designing for, and integration of, birdstrike resistance are identified.

INTRODUCTION

Technology for analysis, test and enhancement of aircraft windshield system birdstrike resistance is being developed and applied by the Flight Dynamics Labor ry of the USAF Wright Aeronautical Laboratories. In the area of birdstrike capab ity analysis our primary emphasis, since the 1981 meeting of BirdStrike Committee Europe (BSCE 15) has been on exploration of capabilities and limitations of the M birdstrike structural analysis computer program. In the area of birdstrike test primary emphasis since BSCE 15 has been on development of an economical and effic technique for quantification of windshield systems deflection during a birdstrike test. In the area of birdstrike capability enhancement our primary emphasis sinc BSCE 15 has been development of improved windshield systems for the T-38 and the aircraft. These efforts to improve windshield system birdstrike resistance have drawn attention to the need for improved understanding of the interrelationship between birdstrike loading and transparency deformation, and the effects of aging degradation of transparency birdstrike resistance.

BIRDSTRIKE CAPABILITY ANALYSIS

Background

The Flight Dynamics Laboratory (FDL) has been involved with the development bird-impact-resistant aircraft transparencies since 1972. As early as 1975, int began to grow in the application of analytical tools to the design of new transp ency systems.

By 1979 the search for a useful transparency analysis tool, resulted in FDL adoption of a nonlinear finite element analysis system called MAGNAM (Materially Geometrically Nonlinear Analysis).

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The MAGNA nonlinear finite element analysis system was developed by the University of Dayton Research Institute, Dayton, Ohio and first became operational during the summer of 1978. MAGNA was designed for the analysis of large scale problems involving three-dimensional structures. It can account for the effects of both geometric nonlinearity (large displacements and rotations) and material nonlinearity (elastic-plastic behavior). The static, dynamic, or free vibration response of a structure can be analyzed using MAGNA. Special features such as contact analysis (e.g. bird/canopy contact, or canopy/heads-up-display contact), full restart capabilities, and convenient interactive graphics make it a powerful analysis tool which is easy to use.

MAGNA was first tested to demonstrate its geometric nonlinearity capability for the transparency bird impact problem during 1980. Results showed that it was capable of realistically reproducing the results of even the most severely nonlinear bird impact test.[1] Doubt was cast though on its validity for use in the design of new relatively flexible transparencies.

The obstacle preventing use of MAGNA as a design tool for flexible transparencies was the fact that the bird impact loading was strongly coupled to the dynamic response of the transparency. This phenomenon will be referred to as "load/response coupling. The primary loading parameters such as footprint area on the transparency surface, period of the impact event, and impulse delivered to the transparency were found to be very sensitive to the instantaneous deformed shape and rates of deformation exhibited by the transparency itself. If the response of the transparency was sufficiently stiff, the footprint area, impact period, and impulse were similar to what they would be for a rigid target case. Since it was known how to define these parameters for the rigid target case, it was possible to realistically predict bird impact response. For flexible designs, it was not possible to define footprint area, impact period, and impulse without knowing beforehand something about the response of the structure, so accurate prediction of bird impact response was not possible.

The reason that MAGNA could be used to reproduce test results even for very flexible transparencies was that a method for "artificially coupling" the loads to the response had been developed by the FDL. This method required the existence of some full scale test data, hence precluding use of the same method during the design of a new system which hadn't yet been tested. Artificial coupling of the loads required estimates of both footprint area and impact period to be made from test data such as high speed film records. The method proved quite powerful and worked well for even the most severely coupled cases.[2]

In 1980, then, the outlook for fruitful application of nonlinear finite element methods to aircraft transparency analysis was both good and bad. It looked good because MAGNA had been validated for the analysis of test results for even the most flexible transparency designs.[2] A method of artificially coupling bird impact loading to the computed response had been developed to permit this type of application.[2] At the same time the outlook was bad because it wasn't known at the time how to implicitly calculate loads which were truly coupled to the response which was being computed. This defeated the use of MAGNA as a design tool for relatively flexible transparencies.[2] The thinking at the time was that results of any test could be analyzed with MAGNA and at least some new (relatively stiff) systems could be designed.[2] Plans were implemented to improve these circumstances.

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Validation Studies

The validation studies had two main goals. The first was to validate the use of MAGNA for a variety of transparency types, and the second was to determine whether or not load/response coupling was significant for each type. Four primary system parameters were addressed: structural stiffness, geometrical shape, cross section design, and temperature.

The first factor, structural stiffness, was the principal factor determing the significance of load response coupling and also was one of the factors determining the importance of large displacement effects in the analysis.

The second system parameter addressed was geometrical shape. The curvature of the transparency surface was also a factor (along with stiffness) in determining the importance of large displacement effects.

The third parameter treated was cross section design. The difference between monolithic and laminated design determines to a great extent the complexity of finite element analysis required for bird impact simulation.

The last of the four system parameters encompassed in these studies was temperature. By analyzing transparency systems at cold, ambient, or hot temperatures it was planned to evaluated the importance of thermal strains in the design of bird-impact-resistant transparencies.

Aircraft transparency systems were selected from among those for which full scale data was available to best show the effects of these four parameters on bird impact computer simulation results. The cases which were selected for study were: a flat laminated glass windshield panel - the British Vulcan B. Mk.1 Bomber Centre Windshield, Figure 1; a curved laminated glass windshield panel - the 36 inch x 36 inch Prototype S-1 Aircraft Windshield Test Section, Figure 2; a curved laminated plastic windshield panel - the Acrylic Faced B-1A Aircraft Windshield, Figure 3; and a bubble shaped monolithic plastic one-piece canopy - the F-16A 0.5 inch Polycarbonate Canopy, Figure 4.

This grouping of cases was planned to provide comparative results for stiff vs flexible designs, flat versus curved geometry, monolithic versus laminated design, and hot versus ambient temperatures.

Details concerning procedures and results for each case study have been published.[9]

Future validation studies are planned to include more complex models using new finite elements (such as the laminated shell[3]), newly added features in MAGNA (such as coupling and surface contact[3]), and parametric studies of a variety of bird impact loading definitions.

Conclusions

The following can be concluded relative to birdstrike capability analysis using MAGNA:

BIRDSTRIKE TESTING

Background

Parallel with efforts to develop and apply analytical tools came the realization that techniques would be required to accurately quantify actual deflections during birdstrike testing.

In addition to input for development and evaluation of analytical models and tools, deflection data measured during simulated bird impact testing has some direct applications. Transparency deflection may be an important pass/fail criteria when the inside surfaces are in close prominty to cockpit equipment or the pilots head or where transparency deflection creates a gap through which bird debris can pass.

A method for obtaining deflection histories utilizing Moire' fringes had been developed under an Air Force contract by the University of Dayton Research Institute.[11-12] This Moire' fringe technique requires the transparency to be painted thus making it opaque. Making the transparency opaque prohibited good observation of the initiation of failure points, propagation of cracks, and measurement of the bird loading footprint for MAGNA correlation.

Approach

The method used to obtain the desired deflection involves determining the location of specific points on the transparency in a three dimensional space at time intervals during the bird impact test. Deflections then are computed as artithemtic and vector sums of changes in space position.

To determine the position of points in space, the principles of phototheodolite tracking systems commonly used on test ranges are applied. The system basically consists of two high speed motion picture cameras which view the points on the transparency simultaneously, Figure 5. The position of both cameras and the pre-impact position of points on the transparency must be known. From projected film frames which were exposed simultaneously by the two cameras, positions of the transparency points in the projected frames are measured. From these measurements, direction angles for the line of sight from a given camera to specific points can be calculated. These angles and the point in space for the camera location determine a line of sight for each camera to a specific point. The intersection coordinates for these two lines of sight is the position of the point for the time which corresponds to the film frames used to establish angles, Figure 6. Repetition of this process for successive film frames results in a deflection - time history for the selected points, Figure 7. The technique for solving for the coordinates of the transparency point utilizing the angles and known camera positions is referred to as the "triangulation" method.

Details concerning procedures and results from application of the triangulation method have been published.[13]

Based on a similar recognition of need, a technique similar to that described herein was independently developed by the Saab Scania Co. in Linkoping, Sweden for analysis of birdstrike deflections on the Viggen aircraft windshield.[14]

Conclusions

The following can be concluded relative to birdstrike test data on position using the triangulation method:

1. The triangulation method can be used to obtain deflection time histories for points located on the inside surface of aircraft transparencies during bird impact testing.

2. Transparency behavior and the position of the bird with respect to the transparency can be observed on triangulation camera films.

3. Triangulation camera installations should be considered for any bird impact test where deflection is of interest. Since these films are also useful for observation of the transparency behavior, additional costs may be minimal. Post test decisions can be made concerning which tests and which points should be the subject of triangulation analysis.

4. Comparison of predicted and actual deflections and bird loading footprints can be aided by taping onto the cockpit side of the transparency, a grid pattern which is representative of the grid pattern used in the finite element analysis.

BIRDSTRIKE CAPABILITY ENHANCEMENT

Background

Transparency systems of many USAF high speed aircraft were not designed to tolerate the birdstrike hazard associated with high speed - low altitude flight. Transparency systems for two aircraft included in this category are being developed to reduce the risk of birdstrike penetration into the crew compartment. The aircraft are the F-4 Fighter and the T-38 Trainer, Figures 8 and 9. These efforts are based on prior successful efforts to enhance birdstrike resistance of windshield systems for the F-111 and F-16 aircraft, Figures 10 and 11.

Analysis of F-4 birdstrike statistics showed that during the 10 year period ending March 1981, 30 of the 68 reported birdstrikes against the transparency system resulted in penetration into the crew compartment. In addition to the repair costs associated with these penetrations there were 12 aircrew injuries (some permanently disabling), one aircraft lost, and one aircrew fatality.

Birdstrikes on the T-38 windshield system have resulted, in addition to repair costs, four aircraft lost and three aircrew lost.

As a result of these situations, programs were established to develop transparency systems which would provide four pound bird impact protection capabilities of 500 knots for the F-4 and 400 knots for the T-38.

Approach

The programs to develop new transparency systems for the F-4 and the T-38 are structured around a three phase approach. This approach reflects a common sense acquisitio

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phases of the approach are: I. Quantify current system capabilities, constraints effecting possible solutions; II Upgrade component capabil- mits imposed by some component which is obviously not reasonable to II Design a new system to provide the desired protection level. Obvi- II and III can have significant overlap. If upgrading the weak links ults in attainment of a major portion of the desired protection level an economical, timely manner, then additional resources needed to do a (Phase III) become of questionable payoff.

ts/Status

Details concerning procedures and results of efforts to define and enhance the and T-38 windshield system birdstrike resistance have been published.[15,16,17,18]

Based on results of the F-4 baseline birdstrike testing, windshield panels ble of providing a 350 knot birdstrike protection are now being obtained to ofit selected aircrafts. A new windshield capable of *providing the desired 500* otection is being developed and canopy modification are being examined to dstrike resistance within weight growth limits which will not necessitate ion of canopy opening and ejection mechanisms.

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apability Enhancement Conclusions

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CONCLUSION

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consideration of what can and cannot be changed based on the need to balance mission effectiveness, hazard tolerance, supportability and cost of ownership.

The three phases of the approach are: I. Quantify current system capabilities, and identify constraints effecting possible solutions; II Upgrade component capability to the limits imposed by some component which is obviously not reasonable to change, and III Design a new system to provide the desired protection level. Obviously Phases II and III can have significant overlap. If upgrading the weak links (Phase II) results in attainment of a major portion of the desired protection level and does so in an economical, timely manner, then additional resources needed to do a total redesign (Phase III) become of questionable payoff.

Results/Status

Details concerning procedures and results of efforts to define and enhance the F-4 and T-38 windshield system birdstrike resistance have been published.[15,16,17,18]

Based on results of the F-4 baseline birdstrike testing, windshield panels capable of providing a 350 knot birdstrike protection are now being obtained to retrofit selected aircrafts. A new windshield capable of providing the desired 500 knot protection is being developed and canopy modification are being examined to increase birdstrike resistance within weight growth limits which will not necessitate requalification of canopy opening and ejection mechanisms.

A new windshield capable of providing 400 knot protection for the T-38 is in the final status of test and evaluation. Operational evaluation of this new design should be completed before the end of 1985.

Birdstrike Capability Enhancement Conclusions

The following can be concluded from current capability enhancement efforts:

1. The baseline test series can confirm the birdstrike problem being experienced with operational aircraft.

2. The baseline testing can quantify the existing capability of the system and generate a data base for designing and evaluating system modifications to enhance the birdstrike resistance.

3. Use of emerging technologies such as described in the two preceding sections can significantly reduce the cost of baseline testing and the cost of developing improved systems.

CONCLUSION

Analysis, test, and enhancement of windshield system birdstrike resistance is necessary to reduce the flight safety hazards of cockpit birdstrike penetration for aircraft assigned to the high speed low-altitude mission. Efforts to develop and apply technology to reduce this hazard have been cost effective. An R&D investment of less than $20 million has resulted in a savings to the USAF in reduced aircraft damage or loss, and in reduced cost-of-ownership, of more than $400 million.

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FIGURES

1. FINITE ELEMENT MODEL: VULCAN B MK1 CENTRE WINDSHIELD
2. FINITE ELEMENT MODEL: 36 INCH x 36 INCH PROTOTYPE B-1 AIRCRAFT WINDSHIELD TEST SECTION
3. FINITE ELEMENT MODEL: B-1 WINDSHIELD PANEL
4. FINITE ELEMENT MODEL: F-16 CANOPY
5. TRIANGULATION SYSTEM TEST SET-UP
6. TRIANGULATION SYSTEM GEOMETRY
7. TRIANGULATION RESULTS
8. F-4 AIRCRAFT
9. T-38 AIRCRAFT
10. F-111 AIRCRAFT
11. F-16 AIRCRAFT

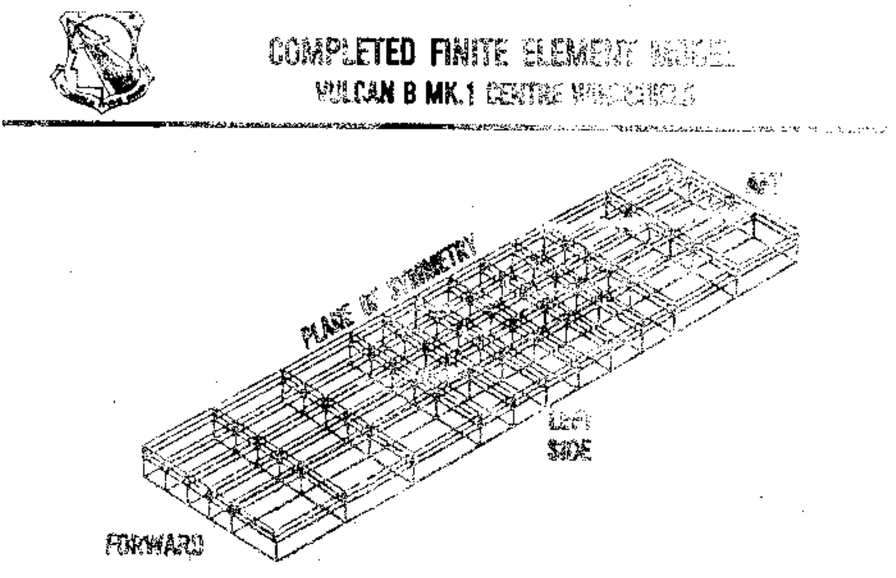


Figure 1 Finite Element Model: Vulcan B MKI Centre Windshield

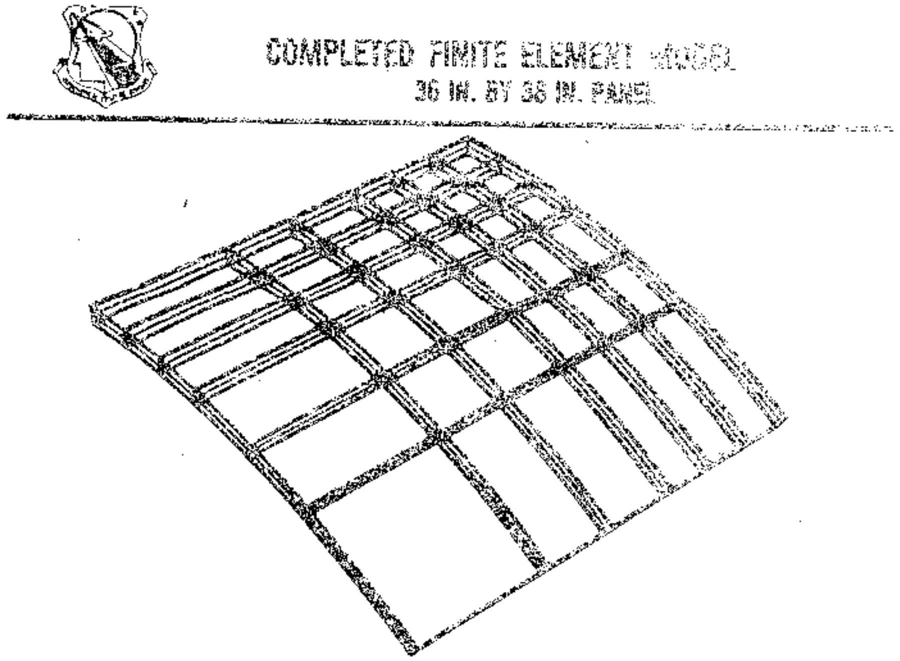


Figure 2 Finite Element Model: Prototype B-1 Aircraft Windshield Test Section

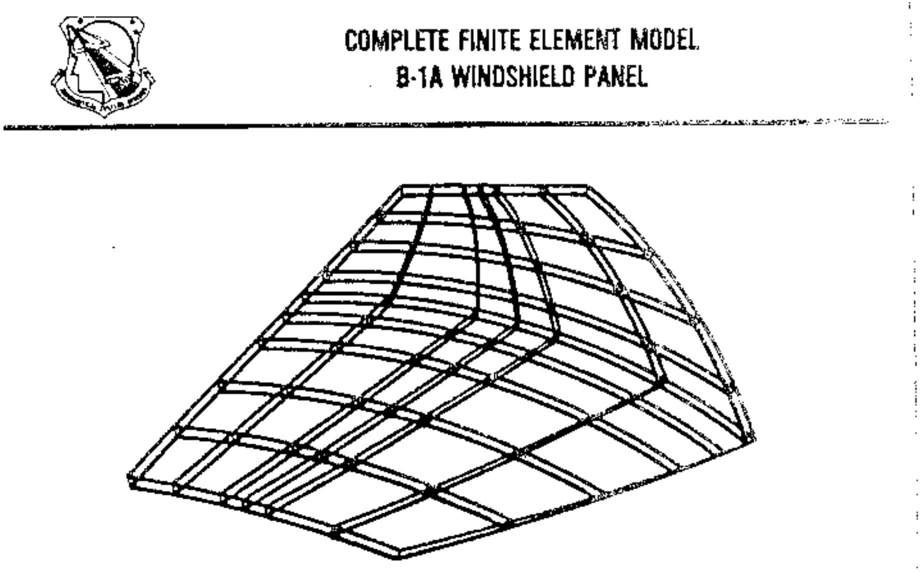


Figure 3 Finite Element Model: B-1 Windshield Panel

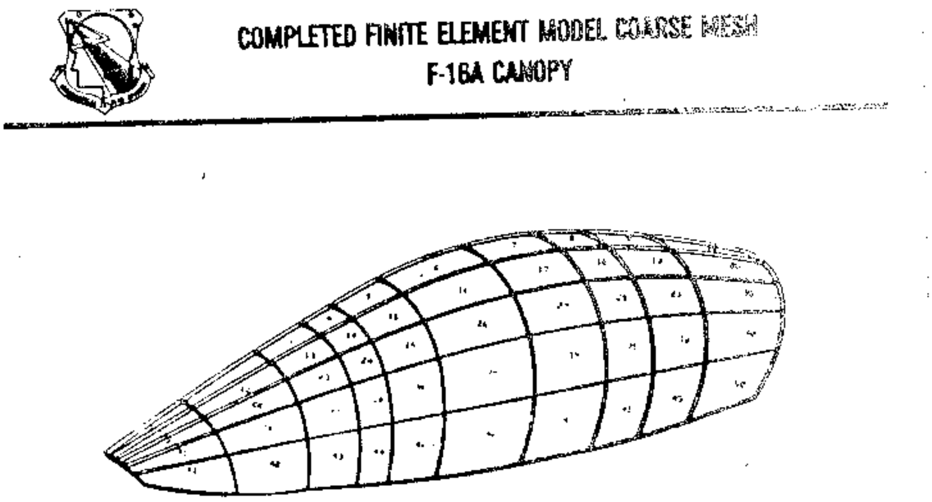


Figure 4 Finite Element Model: F-16 Canopy

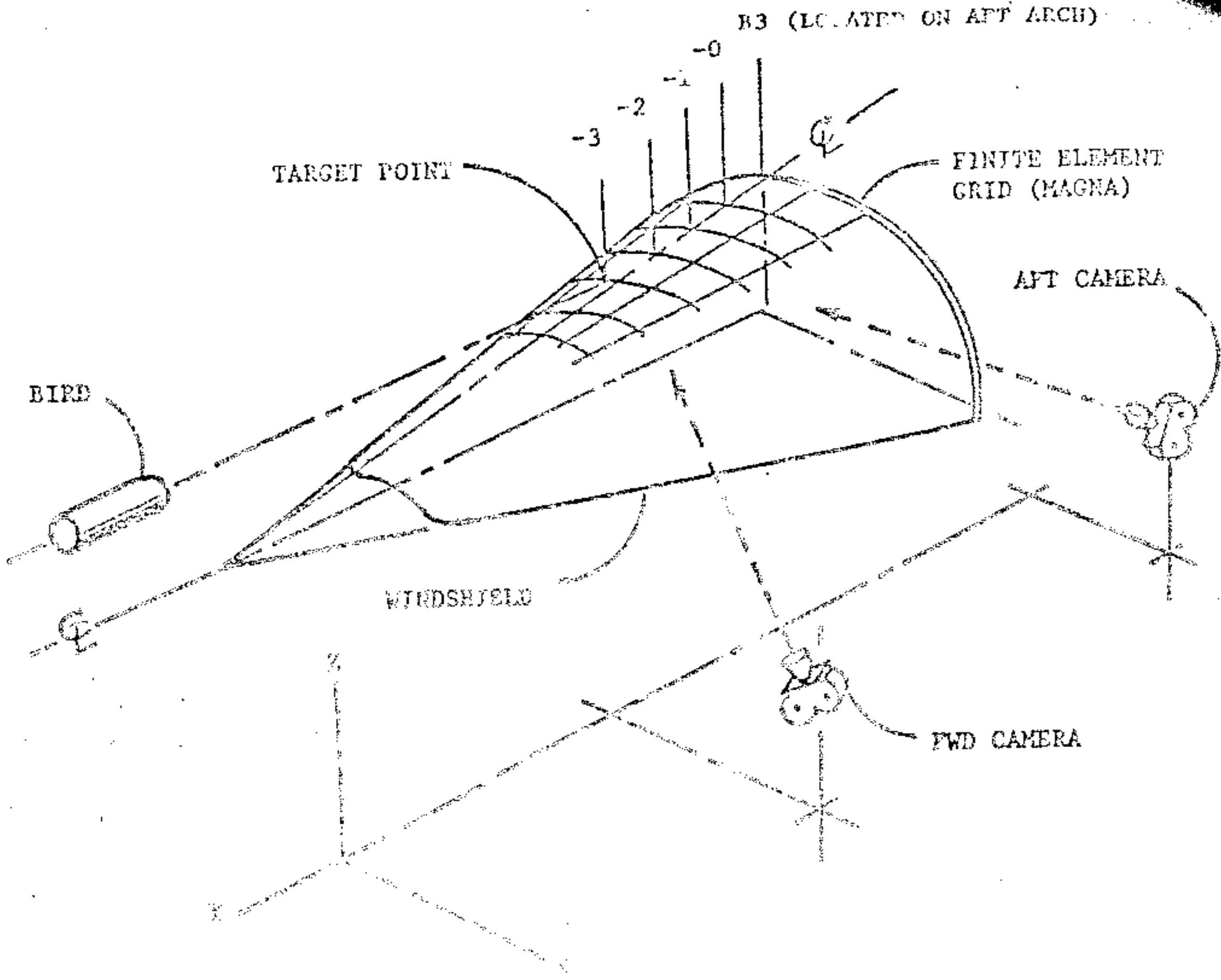


Figure 5, Triangulation System Test Set-up

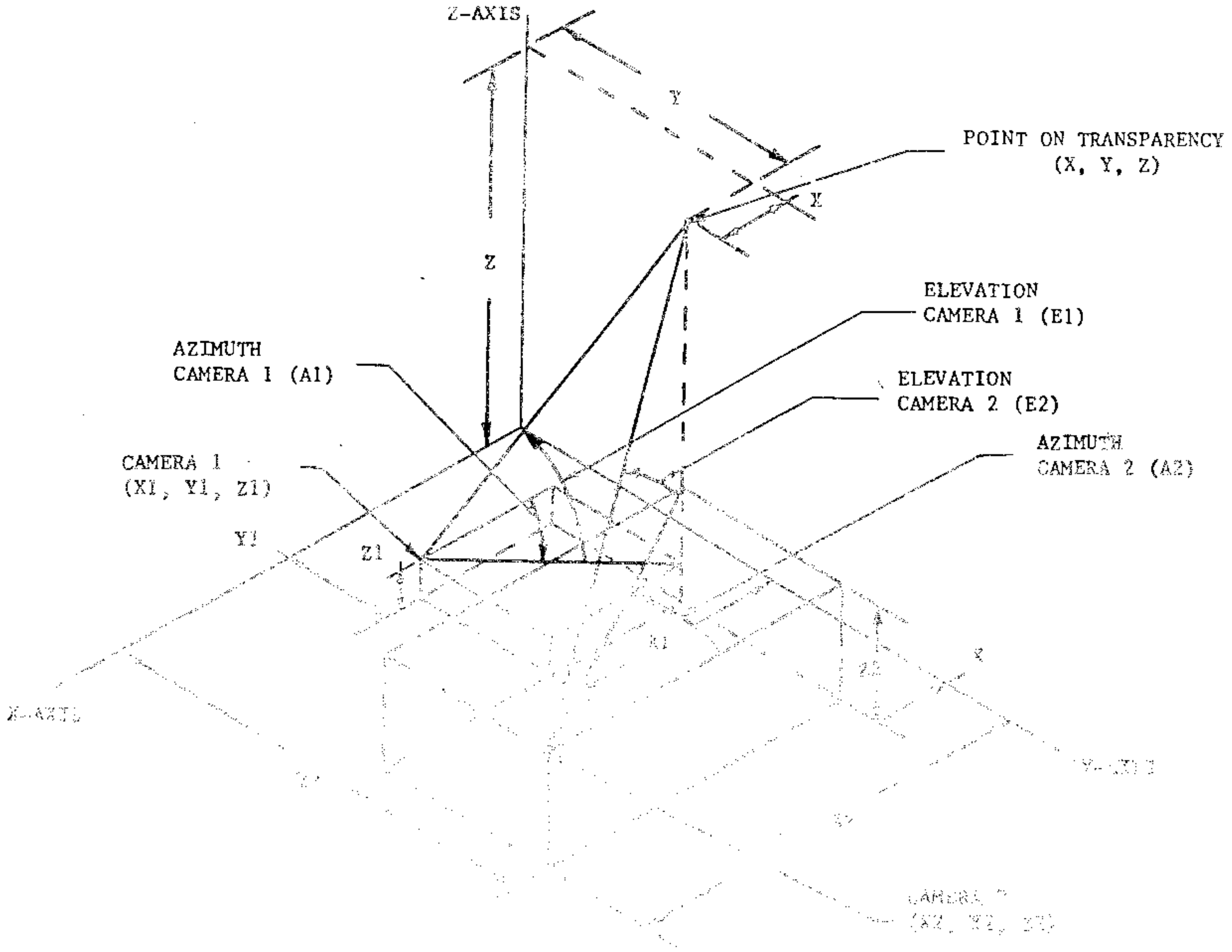


FIGURE 6 TRIANGULATION SYSTEM GEOMETRY

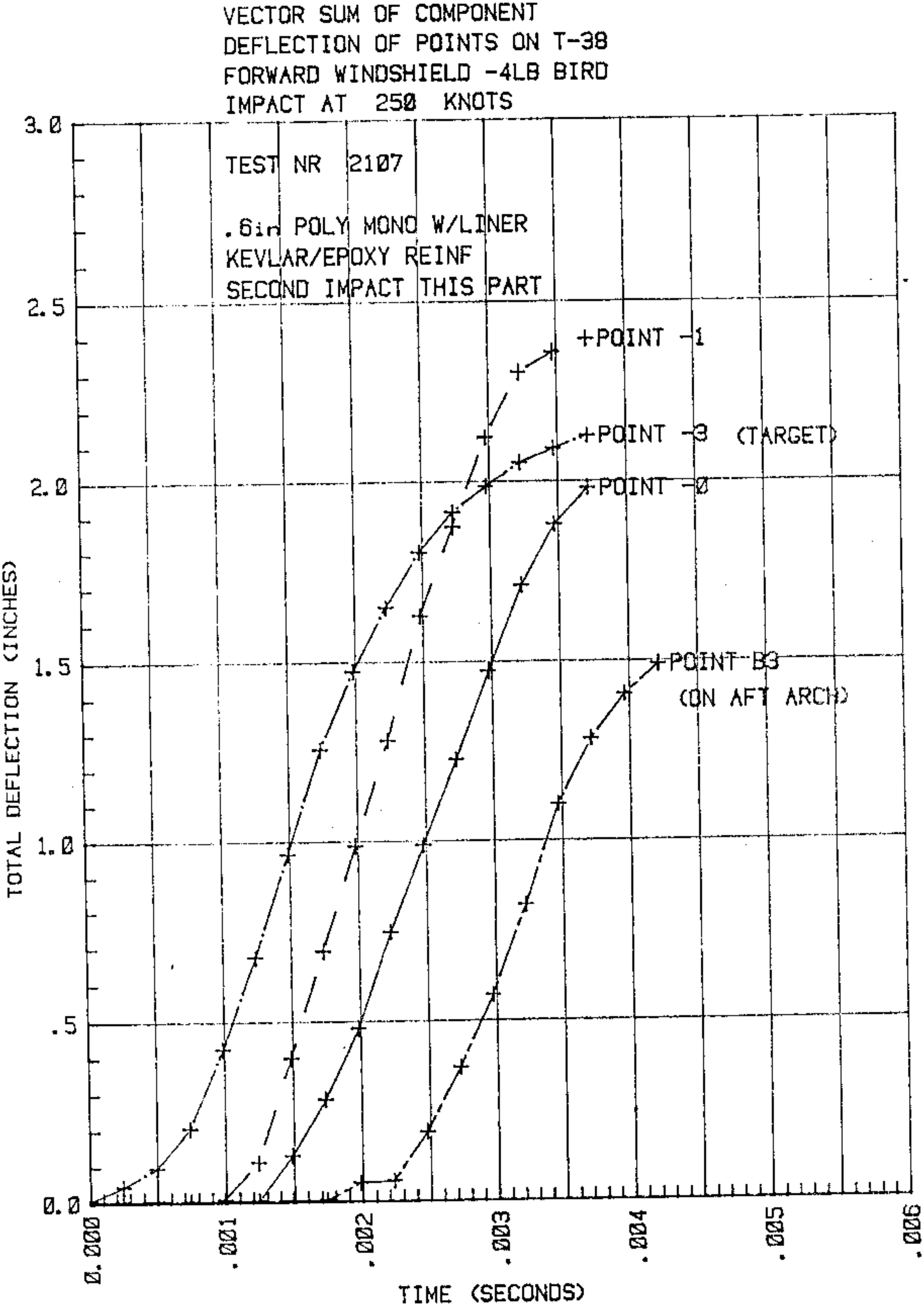


Figure 7 Triangulation Results

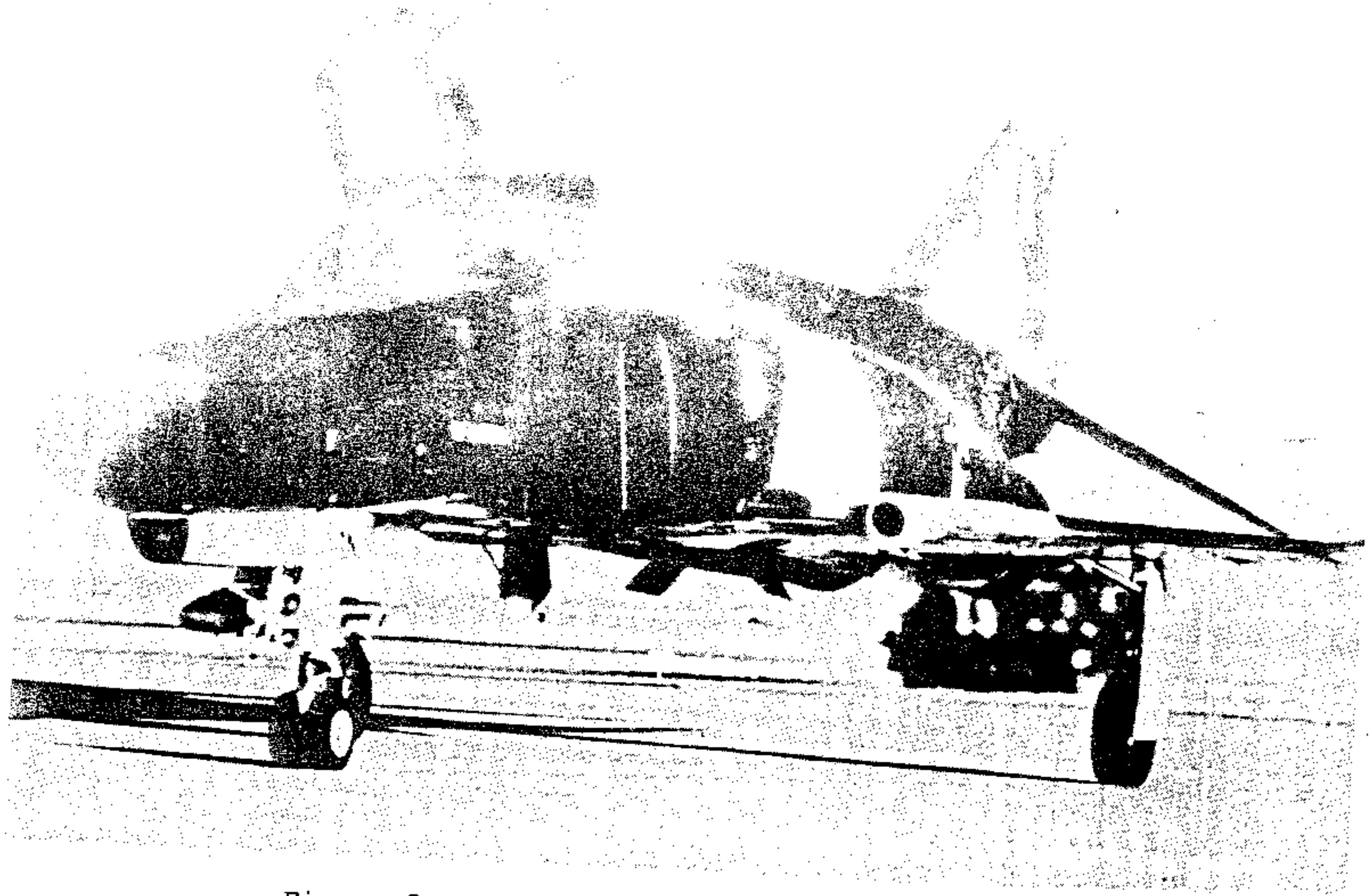


Figure 8. F/RF-4 Aircraft.

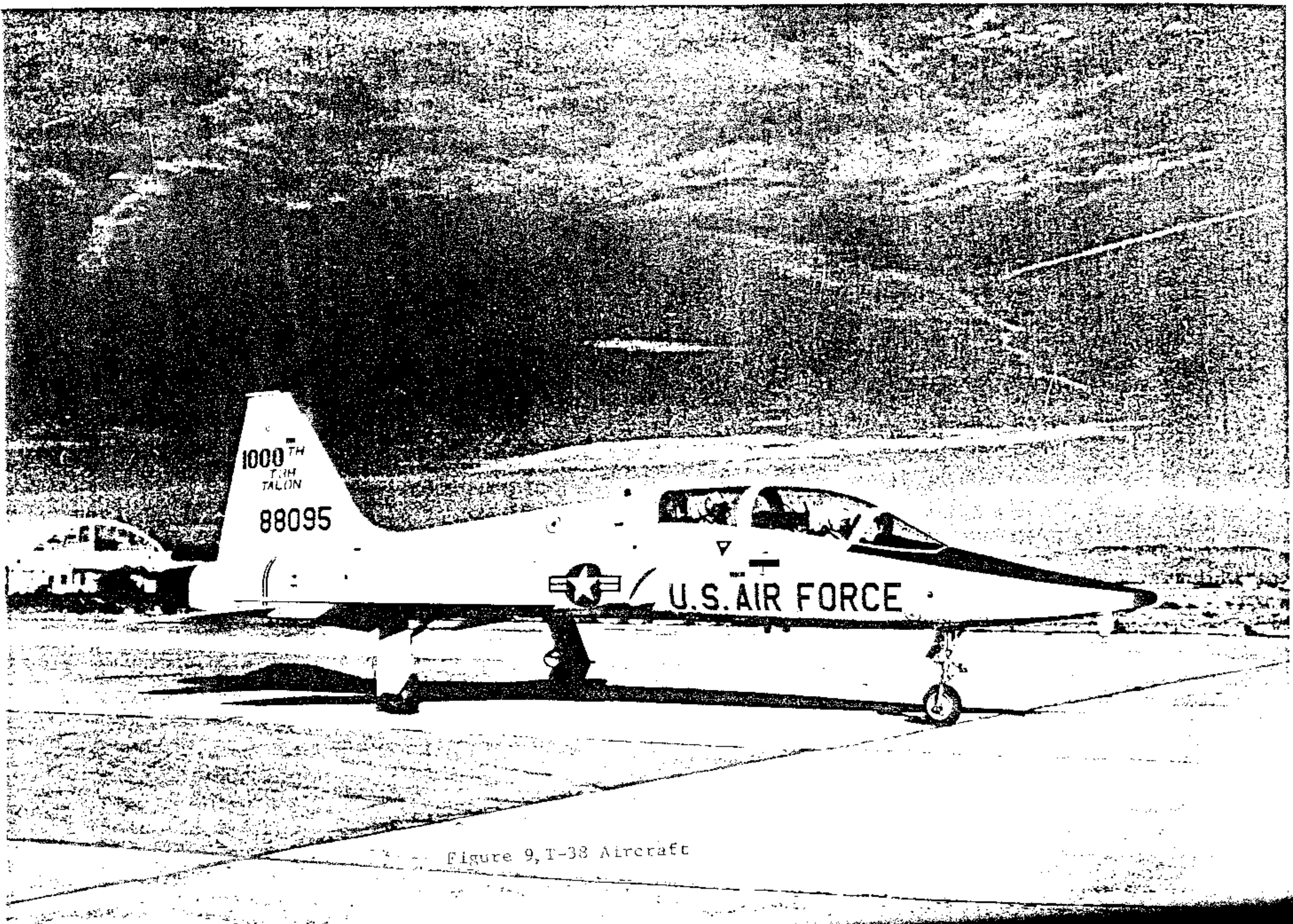
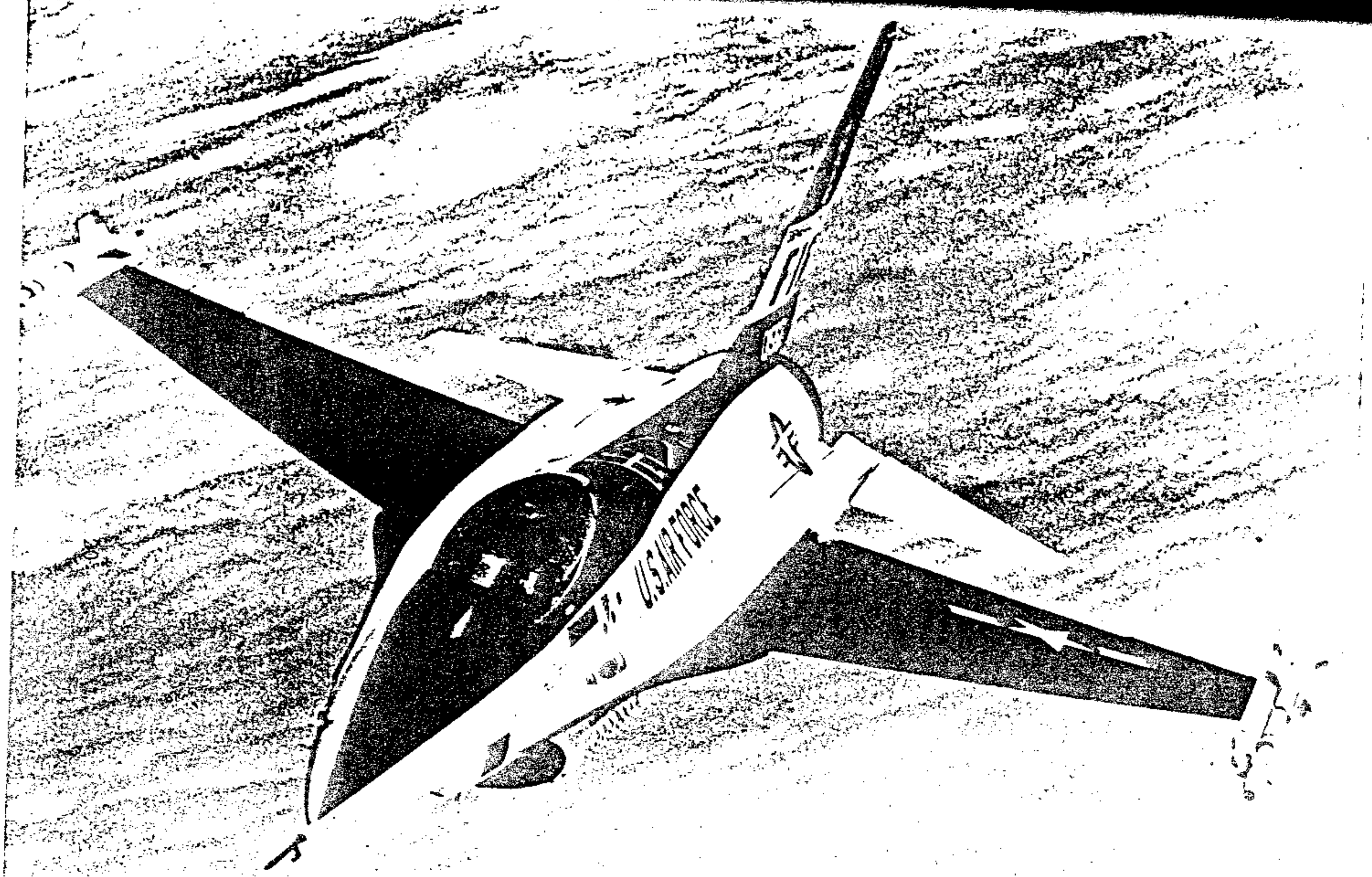


Figure 9, T-38 Aircraft

Figure 10 F-111 Aircraft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