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AIRCRAFT/STORES COMPATIBILITY SYMPOSIUM PROCEEDINGS, HELD ON 18-20 SEPTEMBER 1973, AT SACRAMENTO, CALIFORNIA. VOLUME 1

Joint Technical Coordinating Group for Air Launched Non-Nuclear Ordnance

20 September 1973

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ARMY NAVY

AIR FORCE

VOLUME 1 OF VOLUME 4

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AIRCRAFT/STORES COMPATIBILITY SYMPOSIUM PROCEEDINGS

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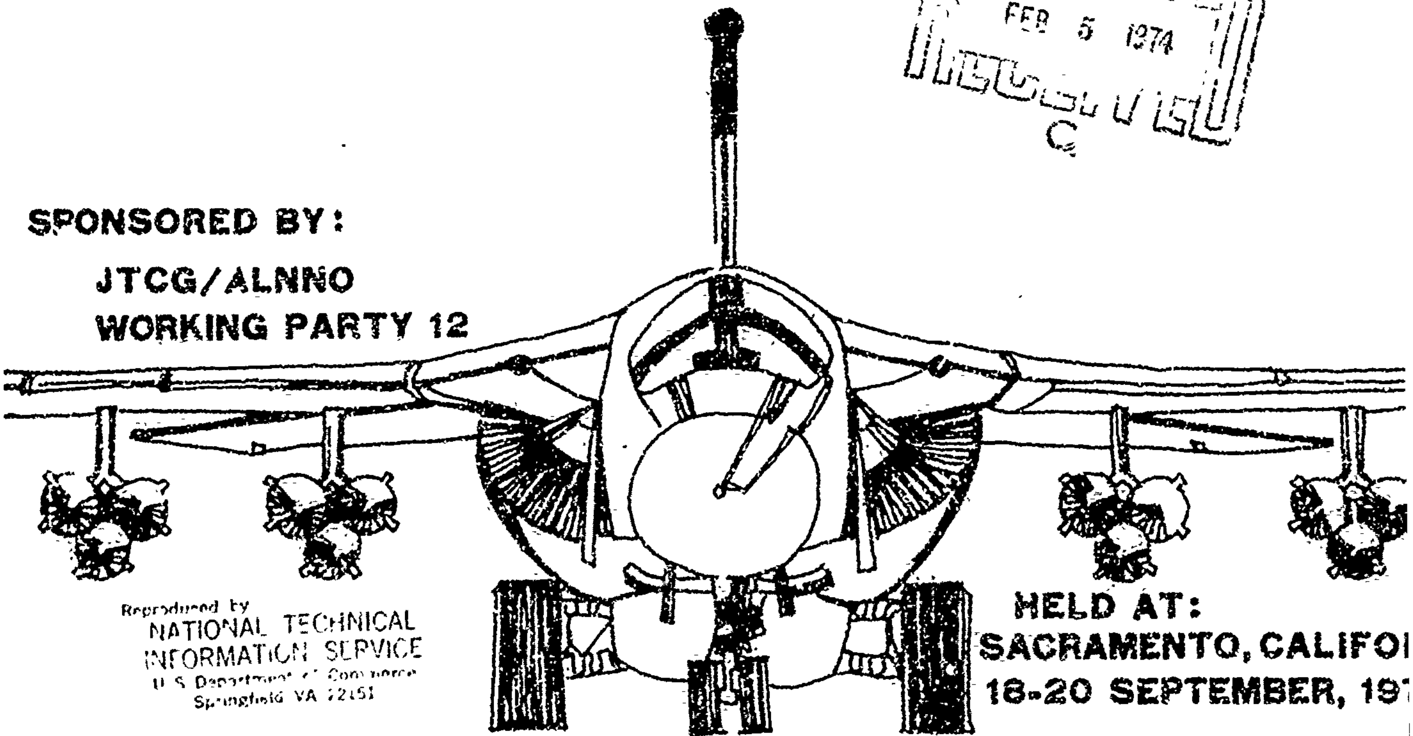

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SACRAMENTO AIR MATERIEL AREA/AIR FORCE LOGISTICS COMMAND,
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AIRCRAFT/STORES COMPATIBILITY SYMPOSIUM PROCEEDINGS

18 - 20 SEPTEMBER 1973

VOLUME I

SPONSORED BY

JOINT TECHNICAL COORDINATING GROUP

FOR

AIR LAUNCHED NON-NUCLEAR ORDNANCE

(JTCG/ALNNO)

PROCEEDINGS COMPILED BY

SACRAMENTO AIR MATERIEL AREA

AIR FORCE LOGISTICS COMMAND

FOREWORD

This publication contains the proceedings of and technical papers presented at the Aircraft/Stores Compatibility Symposium, held at the Woodlake Inn, Sacramento, California on 18 - 20 September 1973. In addition, it contains several other technical papers prepared for the symposium but which were not presented.

The purpose of the symposium was to bring together the technical expertise within Government and industry throughout the world to review and discuss compatibility developments and experiences. Exchanging methods and ideas is essential in present and future systems development. No one organization holds all the answers to aircraft/stores compatibility problems. Solutions to these problems depend upon coordinated efforts by both aircraft and store designers who are aware of the other's requirements.

The symposium committee wishes to express its appreciation to those persons responding to the call for papers--the authors and the presenters--the session chairmen, and the attendees for their contributions in making the symposium highly successful. Special appreciation is extended to Major General George W. McLaughlin, Commander, Sacramento Air Materiel Area, Air Force Logistics Command, for his welcoming remarks in opening the symposium.

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Acknowledgement is made to all those people from McClellan AFB who worked long hours so diligently, cheerfully and efficiently to give us such a pleasant, professional success.

Publication of this report does not constitute Air Force approval of the technical papers' findings or conclusions. It is published only for the exchange and stimulation of ideas.

James C. Phillip

JAMES C. PHILLIP
Chairman, Working Party #12
JTCG/ALNNO

ABSTRACT

These proceedings contain the technical papers presented at the Aircraft/Stores Compatibility Symposium held at the Woodlake Inn, Sacramento, California on 18 - 20 September 1973 which was sponsored by the Joint Technical Coordinating Group for Air Launched Non-Nuclear Ordnance (JTCG/ALNNO). Purpose of the symposium was to bring together the technical expertise within Government and industry to review and discuss aircraft/store compatibility developments and experiences. Technical papers were presented in five different sessions: General, Structural Loads, Store Separation, Aircraft Performance, and Experimental Techniques. Each paper in the proceedings has its own abstract, and contains sections including presentation of data, discussion of findings, and recommendations/conclusions. The compilation of these papers, each focusing on the compatibility problem, should prove extremely valuable to aircraft and store designers by making each aware of the others' technical problems and possible solutions.

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Air Force Logistics Command

OPENING SESSION

INTRODUCTORY REMARKS (not printed)
Mr. J. C. Phillip
Air Force Logistics Command

WELCOME ADDRESS
Major General George W. McLaughlin
Commander
Sacramento Air Materiel Area (AFLC)

JTCG/ALNNO MISSION AND ORGANIZATION
Lt Colonel H. Hansman
Air Force Logistics Command
JTCG/ALNNO Principal Member

WORKING PARTY 12 ACCOMPLISHMENTS
Mr. C. S. Epstein
Air Force Systems Command

Mr. H. L. Washmuth
Navy Materiel Command

WELCOME REMARKS
BY
MAJOR GENERAL GEORGE W. MCLAUGHLIN
SACRAMENTO AIR MATERIEL AREA
AIR FORCE LOGISTICS COMMAND

Good Morning, Ladies and Gentlemen. In behalf of the AFLC Commander and myself, as the SMAMA Commander, I would like to welcome you to Sacramento and to the symposium that you will be participating in for the next couple of days.

I had two reasons for being interested in SMAMA hosting this symposium. One, a selfish reason, in that it gives a lot better opportunity for more of the SMAMA engineers to attend, participate, and get the benefits that accrue from a meeting of this kind. As most of you probably know, we at SMAMA have been the managers for years of many of the fighters. Weapon stores compatibility involves all aircraft but it most consistently involves the fighters. Although the SMAMA people have worked with fighters over the years and have done a good job, there is still much to be accomplished.

The second reason is personal. I have been in tactical operations flying fighter aircraft from World War II up thru Viet Nam; and I always ended up in dive bombing and doing the close support missions. I have seen munitions bump together on other airplanes in the formation. I have seen our own aircraft blown up by their own bombs. From P-47 operations in Europe in 1944 all the way up thru the F-100 aircraft in Viet Nam. As the Director of the TACC (Tactical Air Control Center) I became more familiar with the conditions because of the problems we had with short rounds. Short rounds result from all sorts of reasons; one, human beings. They make mistakes in the setting of switches, etc. Others are due to reasons other than human. Suprisingly, I have seen 500 pound bombs hit the ground and bounce 50 yards after hitting a rock and not detonate until it came to a complete stop. This isn't necessarily incompatibility but may be problems in the bomb mechanism or possibly the attitude of impact. A lot of bombs turn end over end and also, as you know, we have duds. There is no one alive who has flown 300 or 400 missions in close support who hasn't dropped a dud by his own failure in setting the switches or too low a release. There is much important work to be done, even though a lot of outstanding work has been accomplished in the past. The way I look at it, each new

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fighter is a new ball game on weapon compatibility and requires more work.

In going thru your booklet that Jim mentioned, you have many, many interesting papers which are going to be discussed on work that you experts have done on weapon compatibility. So with that, again I welcome you. Anything that hasn't been done to make your stay here enjoyable, be sure to let Jim or some of us know and we will take care of it. Have a good symposium.

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JTCG/ALNNO MISSION AND ORGANIZATION

by

Lt Col H. J. Hansman
Principal Member
Air Force Logistics Command

On behalf of the chairman of the Joint Technical Coordinating Group for Air Launched Non-Nuclear Ordnance, I would like to add my welcome to that of General McLaughlin. I am looking forward to this symposium as a most beneficial event for all of us.

I would like to take a few minutes to acquaint you with the background and current activities of the Joint Technical Coordinating Group for Air Launched Non-Nuclear Ordnance, better known as the JTCG/ALNNO. (Next chart, please.) Our parent organization, if you will, is the Joint Logistics Commanders (JLC), the four Commanders who are responsible for meeting the material needs of the US operating forces. Our JTCG/ALNNO operates under the auspices of the JLC. The JLC principals are the Commanding General of the US Army Materiel Command (AMC), General Henry A. Miley, Jr.; the Chief of Naval Material Command (NMC), Admiral I. C. Kidd, Jr.; the Commander of the Air Force Logistics Command (AFLC), General Jack J. Catton; and the Commander of the Air Force Systems Command (AFSC), General Samuel C. Phillips. These four gentlemen meet quarterly to discuss matters of mutual interest, arrive at a common understanding of each other's position, and decide on courses of action to be jointly pursued. Their management concept has been endorsed by the Office of the Secretary of Defense, and continues to reflect significant interservicing accomplishments. (Next chart, please.)

The Joint Commanders achieve their objectives through numerous coordinating groups and panels. One of these is the JTCG/ALNNO, which was chartered by the JLC on 30 October 1964 and is a very active, continuing organization. Its mission, as shown here, is threefold. Much success has been achieved in establishing a high degree of awareness between the Services at all levels in our particular area, and in the recommendation of specific programs to meet known requirements. As you can imagine, this total effort is a continuing activity covering widely divergent areas of technology. (Next slide, please.)

The lead command for the JTCG/ALNNO is Air Force Systems Command. There are four principal members, representing AMC, NMC, AFLC, and AFSC, with Mr. Roger Hartmeyer from AFSC as the overall chairman.

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These four individuals are authorized to speak and act for their command in their areas of responsibility. They also manage and coordinate the activities of the various working parties within the JTCG/ALNNO.

There are about 330 people in the 15 JTCG/ALNNO working parties. These working parties are, as their name implies, the prime movers who actually accomplish the mission of the JTCG/ALNNO. Each working party has a principal member from his command. Each command representative is a highly-qualified technical expert in the working party's area of interest, and is aware of the related efforts in his command pertaining to that subject. Through regular meetings, the JTCG/ALNNO members have established close technical working relationships between the service development communities. (Next slide, please.)

Shown here are a few of the accomplishments over the recent months for which JTCG/ALNNO can be justly proud. This list is not exhaustive, but is indicative of the type of activities in which the working parties are engaged. As you can see, the activities range from the elimination of tetryl from munitions, to the design of a container retrieval system, to the preparation of a Joint Development Plan (JDP) for a Target Activated Munitions System. Again, these are merely illustrative of the JTCG/ALNNO undertakings.

Of prime interest to us today is another major accomplishment - this symposium - which was arranged by the Aircraft Stores Compatibility working party, under the chairmanship of Mr. Jim Phillip from SMAMA. I would like to thank Jim, his committee, and all their able assistants for the excellent work they have done in organizing this event. The success of their efforts is obvious from the number of active participants here today. I am most pleased to turn the podium over to the AFSC Principal Member for Working Party 12, Mr. Charles Epstein.

JTCG/ALNNO

JOINT
TECHNICAL
COORDINATING
GROUP
AIR
LAUNCHED
NON-
NUCLEAR
ORDNANCE

JTCG/ALNNO

THE JOINT LOGISTICS COMMANDERS (JLC)

(AMC/NMC/AFLC/AFSC)

THE JOINT LOGISTICS COMMANDERS (JLC)
(AMC/NMC/AFLC/AFSC)

TITLE: AIR LAUNCHED NON - NUCLEAR ORDNANCE (JTCG / ALNNO)

PURPOSE: PANEL CHARTERED 30 OCTOBER 1964 TO:

- *INSURE COMPLETE INTERSERVICE AWARENESS OF TOTAL R&D PROGRAM IN THE ALNNO AREA
- *RECOMMEND REORIENTATION OF SPECIFIC PROGRAMS
  - *TO INSURE MAXIMUM UTILIZATION OF RESOURCES AND CONSOLIDATED APPROACHES TO MEET SIMILAR REQUIREMENTS
- *REVIEW ALL NEW AIR MUNITION DEVELOPMENTS
  - *FOR MAXIMUM INTERSERVICE DESIGN STANDARDIZATION AND INTERCHANGEABILITY

EXPECTED COMPLETION DATE: CONTINUING

LEAD COMMAND: AIR FORCE SYSTEMS COMMAND

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- PRINCIPLE MEMBERS

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L/C H. J. HANSMAN, AFLC
CHARLES BRANDON, AMC
ED FISHER, NMC

- WORKING PARTIES

EXPLOSIVES
MISSILES & ROCKETS
FIRE CONTROL
GUNS
PYROTECHNICS
SHIP / STORE CONTAINERS
FLAME & INCEDIARY DEVICES
WARHEADS
FUZES
BOMBS, CLUSTERS, DISPENSERS & AIR DELIVERED LAND MINES
RACKS & EJECTION CTGS
AIRCRAFT / STORES COMPATIBILITY
FUEL AIR EXPLOSIVES
MUNITIONS HANDLING & LOADING EQUIPMENT
LASER ORDNANCE APPLICATION

JTCG ALNNO
RECENT ACCOMPLISHMENTS

- ELIMINATION OF TETRYL FROM MUNITIONS
- REVISED FUEL AIR EXPLOSIVES TECHNOLOGY PLAN FOR INCLUSION INTO JSEXP
- PREPARED DETAILS OF A TRI-SERVICE CONTAINER DESIGN RE-TRIEVAL SYSTEM
- CONDUCTED DETAILED REVIEW OF RELATED DOD FUZE DEVELOPMENTS IN CONTEXT OF SERVICE REQUIREMENTS
- PREPARED JOINT DEVELOPMENT PLAN FOR AIR DELIVERED TARGET ACTIVATED MUNITION SYSTEM

WORKING PARTY 12 ACCOMPLISHMENTS

BY

MR. C. S. EPSTEIN - AFSC
MR. H. L. WASHMUTH - NMC

I don't know what Col Hansman has been doing, but I know what I've been doing.

I would like to add my welcome to all of you for being here at this second symposium sponsored by the JCTG. At this particular time, I would like to recognize our foreign visitors. Through considerable effort and some trials and tribulations, we have with us representatives from the United Kingdom - from Government as well as Industry; we have Canadians, Israelis, Germans, and Australians. I hope - I haven't seen some of them yet but they said they were coming. It is our hope that this symposium will institute something that we haven't had in the past - a kind of international cooperation in this type of work. After all, that's the name of the game; to put the information out before you, to make contacts, to find out what the other fellow is doing. Already I have found out some interesting things from overseas and am looking forward to additional participation by our overseas friends.

This symposium is sponsored by the JCTG/ALNNO but primarily Working Party 12. Working Party 12 is Aircraft Stores Compatibility, and we in the committee are extremely proud of what we have accomplished - and rightly so. The JCTG for Munitions Effectiveness have published the JMEM manuals which many of you have seen. Perhaps they have outdone us in terms of weight in paper work that they have put out, or volume of file cabinets. But nevertheless, we have succeeded in the last three or four years and recently published several documents. The first of which was a Military Standard, Mil Standard 1289, which covers all tests and compatibility tests on the ground for airplane and store. I think this was sort of a milestone in that in it we have for the first time drawn together all Army, Navy, and Air Force requirements for that subject.

Also not too long ago, the second thing that we published was a handbook, Guide to Aircraft Stores Compatibility. Many of you have this handbook but if you don't and would like to have it, please contact me. It is another first. A design manual, if you will, available to the engineer who is in the business of compatibility. It is for the aircraft designer, the rack designer, and the bomb or weapon designer. There is a section in it for each of you. This volume has been published on a one-time issue with a blue cover, JTCG/ALNNO. We are concurrently having this document made into a Mil Handbook, I think. There seems to be some doubt about that at times but it will be a regular official document and publication should be within the next year I went ahead and published this guide in the meantime so that people could be using it.

The third document, the Aircraft Stores Interface Manual, you will be able to see out there on the table. This document covers aircraft stores drawings and interface drawings. I am not going to talk about it because I am going to have somebody else up here in just a minute. We have published these three documents within the last year, and we think that they are very useful. It is the first time that anything like this has ever been published in our field.

Our committee, Working Party 12, is now looking beyond these documents for other tasks. In our particular committee, we are now starting to work on standardization of flight testing procedures for aircraft stores compatibility test. This is our next major goal, to come out with a flight test document. Our working party is divided into three work study groups: an electrical mechanical study group headed by Mr. Hoffman from the Armament Lab; a structural study group headed by Mr. Bill Steeper from NAVAIR; and an aerodynamic study group of which I am the head. We all work together to put out these documents and we hope that they will be of some value to you. They are not of any value to any of us, if you (I guess you are pretty much the customers) do not use them. If after seeing these documents, you have any comments, it is not too late to make changes to them; that is what they are here for. We invite your participation in helping us to get out a document that is useful to everyone. So please take it that way. We are receptive to constructive criticism. We are not too receptive to some criticism, like everyone else, so I stress - constructive, constructive criticism. We would like to have your participation in helping us get these documents in the best possible shape. So if there is anything we can do to improve what we have now, we would like to know about it.

Now I would like to turn the podium over to Mr. Harold Washmuth of China Lake who is going to tell you about this document that, as a matter of fact, just came out the other day.

As Charlie mentioned, I am Harold Washmuth from the Naval Weapons Center, China Lake, California. I have just published and prepared for distribution the Aircraft Stores Interface Manual for the JTCG/ALNNO. This is a copy of the volume and we have several out in the lobby that you people can look at during the next few days.

In general, it is a compilation of the physical arrangement of aircraft. There are about 150 1/16-inch scale drawings on aircraft; in general, preview type drawings. There are about 70 drawings on bomb racks. These give the footprints and the physical geometry of bomb racks that would interface with the store. In the front of the manual is a short text which basically describes the drawings and their intended use. Also, a short text on how they can be used. I am sure that you people will find ways of your own to use them. I am very interested in your comments on this, particularly in any corrections that might be made; errors, things that need to be added to the drawings and things that you people find in present an interference problem. Also in the front of the manual is a basic description of the ways to write something up on this and send it in to us. As far as I am concerned, this can be very informal. But basically there are a few guidelines given as to what you may wish to add and some reasons as to why it should be added. I, for one, am very happy to add useful data. There are some plans for making additions to the manual, such as more pylon details, access to the pylons, etc.

A copy of the distribution list, which is just typed and not included in the manual, will be inserted in the manuals out in the hallway. I would like you to go over this list and see if you are listed and if the listing is correct. If you would like to be added to the distribution list, write the information needed on the sheet of paper provided; distribution will probably be within the next 30 days.

In general, the distribution is broken down in this way. The Army, AASCOM, St Louis - Mr. Cobb has asked for the complete Army distribution and he will distribute them within the Army. The Air Force has essentially broken their distribution down to their AMAs and Logistic Command. In their System Command, all copies will go to Mr. Hoffman at Eglin. If you are located at Eglin, I would prefer that you request a copy from Mr. Hoffman direct. If for some reason this does not work out, then I would be glad to have this input. Major aircraft manufacturers will be on the distribution list.

Is the JTCG organization going to continue to come up with funding for this? If so, we will then continue our work and add to the manual in the future. If you have any further questions regarding this matter, I shall be here at the symposium and around for the rest of the week and will be happy to answer them.

At this point, I would like to introduce Mr. Chuck Hoffman from Eglin Air Force Base, Chairman of the first session and also chairman of our Electrical Mechanical Section in Working Party 12.

SESSION 1

GENERAL SESSION

Chairman

Mr. C. R. Hoffman
Air Force Armament Test Lab
Air Force Systems Command

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SUSPENSION EQUIPMENT CONSIDERATIONS

(U)
(Article Unclassified)

ROBERT L. KYLE

Douglas Aircraft Company
Long Beach, California

ABSTRACT (U)

The Douglas Aircraft Company of the McDonnell Douglas Corporation has maintained a continuous research and development Armament Technology Program. One of the products of this program is a computer simulation of an ejector rack. Ejector force, pressure and store position versus time are outputs of this program. A preliminary error study has been performed in the areas of mechanism design tolerance, hook loads and temperature effect on ejector operation. At the present time, this computer program is being combined with AF Flow Angularity Program to obtain a general program for store separation and ground impact error studies on present and advanced ejector concepts.

High-density bluff NSRDC Star Fin munitions appear to offer appreciable promise when carried conformally. However, in adopting a completely new weapon, considerable time is required for development and production until the weapon is available in quantity for large-scale service usage. Consequently, an interim high-density store approach through conversion of the existing general purpose bombs to NSRDC Star Fin shapes would appear beneficial. The results of a weapon conversion study indicate that a reasonable NSRDC shape simulation can be achieved with the general purpose converted bombs consisting of two natural module lengths which allow easy conformal carriage or multiple carriage pylon palletization with fixed ejectors.

Public Release Approved

INTRODUCTION

The Douglas Aircraft Company of the McDonnell Douglas Corporation has maintained a continuous research and development program known as the Advanced Armament Technology Program. This program has addressed high-speed aircraft carriage, release and ground impact problems associated with free-fall conventional weapons. In November 1967, the Douglas Aircraft Company performed a low drag store carry study while under contract to the Naval Ship Research and Development Center (NSRDC). This study established the aerodynamic gain associated with fuselage conformal carriage of weapons. Since this contract, Douglas has performed numerous supporting studies to the conformal carriage effort under the Advanced Armament Technology Program.

Special weapon suspension equipment considerations are encountered with fuselage conformal carriage pallets. A high-energy ejection system is advantageous to ensure safe store separation from the pallet and reduce the influence of the interference flow field on the entire trajectory and eventual impact point on the ground. In addition, the ground handling accessibility is very limited in pallets especially for the center row of ejectors when three or more rows are used. Upon noting these requirements, a design study was initiated to develop an ejector rack that is completely compatible with conformal or pallet mounting of ejectors. From this study, the Submerged Profile Ejector Racks (SUPER) design was conceived.

The SUPER-14 rack uses a unique lug restraining principle that eliminates conventional sway bracing without requiring changes in the standard MIL-A-8591 C or D bail lugs. Instead of conventional sway bracing, a self-adjusting wedge provides the necessary sway-bracing restraint when the rack hooks are latched during store loading. This automatic sway-bracing feature is essential in minimizing aircraft turnaround time. Closely spaced ejector unit installations are feasible where conventional sway-bracing techniques are impractical. In addition, totally submerged conformal carriage applications are possible. A patent was granted Douglas for the SUPER principle on August 10, 1971.

To obtain the technology necessary to design bomb racks with greater flexibility, an ejector rack gas dynamic analysis was initiated. Current cartridge-actuated-device gas-dynamic theory was applied and evaluated with respect to existing ejector unit empirical data. This theory was then modified to form an analytical base for future designs. This analytical approach was used to design the SUPER-14 high-energy ejection system. SUPER-14 prototype units were fabricated and ejection tests were performed which substantiated the gas dynamic theory employed in the analysis.

This paper describes the Douglas research and development ejector rack gas dynamics computer program that developed from these efforts.

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In addition, a palletized suspension equipment arrangement study is presented and discussed which further complements conformal carriage of weapons.

EJECTOR RACK COMPUTER SIMULATION

To obtain the complete force versus time curve of the ejector, the gas dynamic analysis was programmed for the IBM 360 digital computer. In addition, the release mechanism characteristics were simulated to obtain release time information. SUPER-14, 1810 (MER-200), LODE-14 (BRU-3A) and 9610 (MER-7 or MER-10) bomb rack characteristics were determined which provides ejector simulation of the newer Douglas designed racks. With this computer model, which simulates cartridge actuated bomb rack operation, the effect of hook loads, environment, tolerances and cartridge variations can be analyzed to determine the magnitude of bomb rack error contributions.

COMPUTER VARIABLES

A number of cartridge, ejector unit and store variables are input to the ejector rack model. A partial list of these variables is given below.

Cartridge Variables:

- Type used
- Number used
- Booster charge weight
- Booster charge density
- Booster charge burning rate
- Booster charge average molecular weight
- Booster charge gas constant volume specific heat
- Main charge weight
- Main charge web thickness
- Main charge density
- Main charge burning rate
- Main charge average molecular weight
- Main charge gas constant volume specific heat
- Total volume of empty cartridge
- Ambient air temperature
- Ambient air pressure

Ejector Unit Variables:

- Breech total volume
- Breech heat loss characteristics
- Aft end housing initial volume
- Forward end housing initial volume
- End housing heat loss characteristics
- Aft orifice diameter

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Forward orifice diameter
First piston stroke length
First piston area
Second piston stroke length
Second piston area
Release characteristics of ejector unit

Store Variables:

Store weight
Store radius
Pitch mass moment of inertia
Yaw mass moment of inertia
Roll mass moment of inertia
Distance cg to aft piston
Distance cg to forward piston
Inertial initial loading
Aerodynamic loading

TEST DATA CORRELATION

Excellent correlation with test data has been obtained with this computer simulated ejector rack model. Figure 1 shows a comparative plot of computer model obtained data versus test data for the SUPER-14 ejector unit. Similar correlation has been obtained for other store weights and the 9610, LODE-14 and 1810 ejector racks. In addition to force versus time data, breech and ejector pressures are determined and can be output as a function of time. Vertical and lateral store positions and angular position and velocity are also computed and output to further describe the ejection event. Through this theoretical computer approach, the effect of environment and external loads on the ejection system can be determined at low cost without expensive instrumented tests being performed.

PRELIMINARY ERROR STUDY

A preliminary error study has been performed in the areas of mechanism design tolerance, hook load effect and temperature effect on ejector operation. As an example of this application, Figure 2 shows the effect and manufacturing tolerance on the release time to hook opening for the 9610 and SUPER-14 bomb racks. Three manufacturing tolerance conditions were investigated with the computer model: (1) the tolerance extreme that provides minimum locking; (2) the nominal tolerance condition that provides average locking; and (3) the tolerance extreme that provides maximum locking. An examination of these curves shows that release time and release time spread for tolerance variation for the SUPER-14 is considerably less than that of the 9610. The SUPER-14 utilizes a new hook release mechanism which is superior to the 9610 release mechanism as shown by the results of Figure 2.

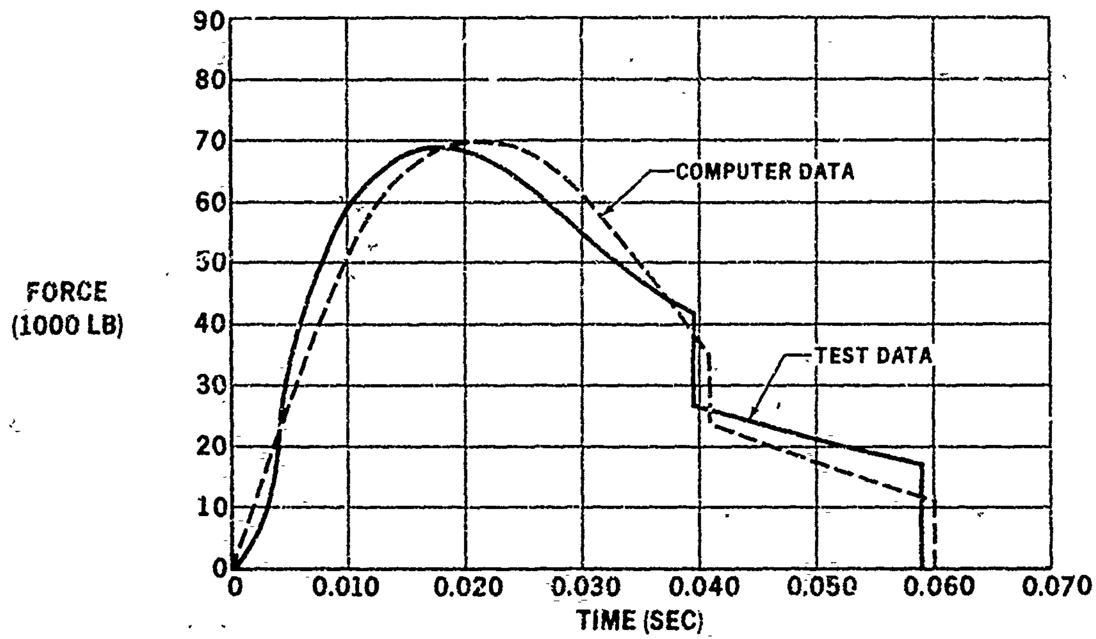

FIGURE 1. SUPER-14 COMPUTER VERSUS TEST DATA

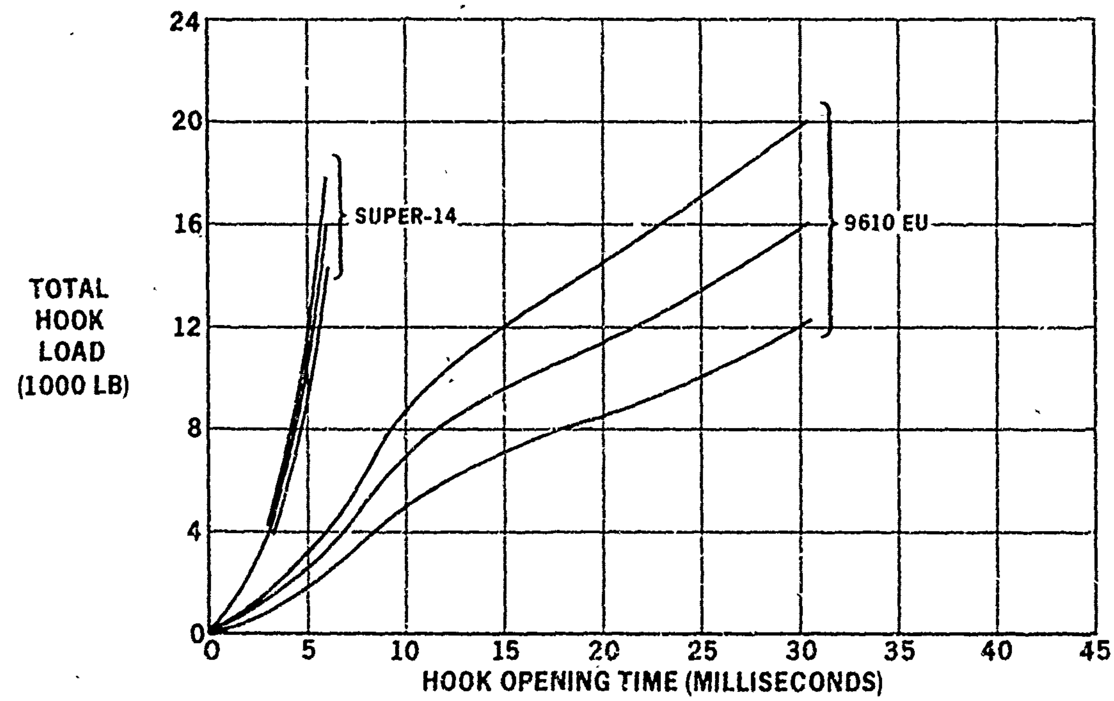

FIGURE 2. MANUFACTURING TOLERANCE EFFECT

High hook load effects are shown in Figures 3 and 4 for the 9610 and SUPER-14 respectively. Although very little variation in end-of-stroke (EOS) velocity was obtained with the 9610 or SUPER-14, an appreciable variation in overall impulse time resulted for the 9610 but not for the SUPER-14. As before, the SUPER-14 superior release mechanism is illustrated by these results. Very little temperature effect was obtained for the 9610 or SUPER-14. However, Figures 5 and 6 demonstrate a subtle temperature effect for the LODE-14 without, and with orifices. Figure 5 shows that without orifices the LODE-14 EOS velocity varies by 3.5 ft/sec from -65 to 160°F. When 0.089 orifices are installed this temperature effect is reduced to a 1.2 ft/sec variation as shown by Figure 6. This observation indicates that even if orificing is not required for pitching, equal orifices are beneficial toward eliminating a major portion of the temperature effect with the LODE-14.

GROUND IMPACT ERROR

An investigation of the ground impact error associated with the effects of mechanism tolerance, hook load and temperature was performed using an Eglin error analysis based on a free-stream ballistic approach. This study indicates that an 18-foot impact error can result for typical MER hook loads for the 9610 due to mechanism tolerance. Whereas, a 2-foot impact error is associated with the SUPER-14 for identical loading conditions. The high hook load effect on total impulse indicates a 15-foot error for the 9610 and zero error for the SUPER-14. A 77-foot temperature effect impact error is indicated for the LODE-14 without orifices and a 12-foot error is indicated for 0.089 orifices. However, this free-stream ballistic impact error treatment leaves a great deal to be desired, because the aircraft interference flow field has been ignored totally.

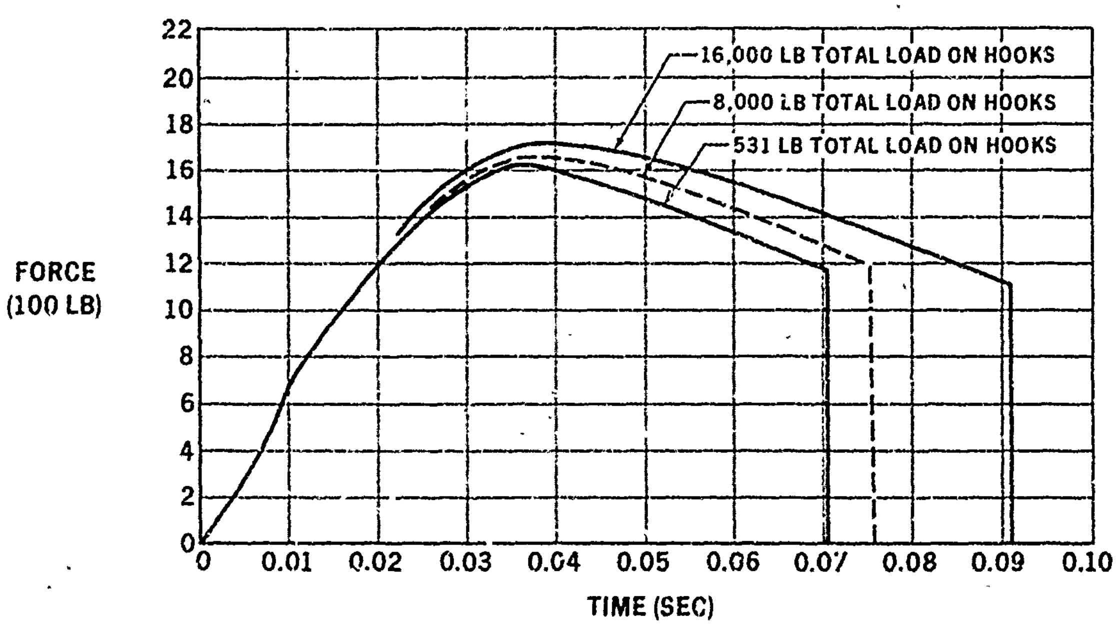

FIGURE 3. 9610 HIGH HOOK LOAD EFFECT

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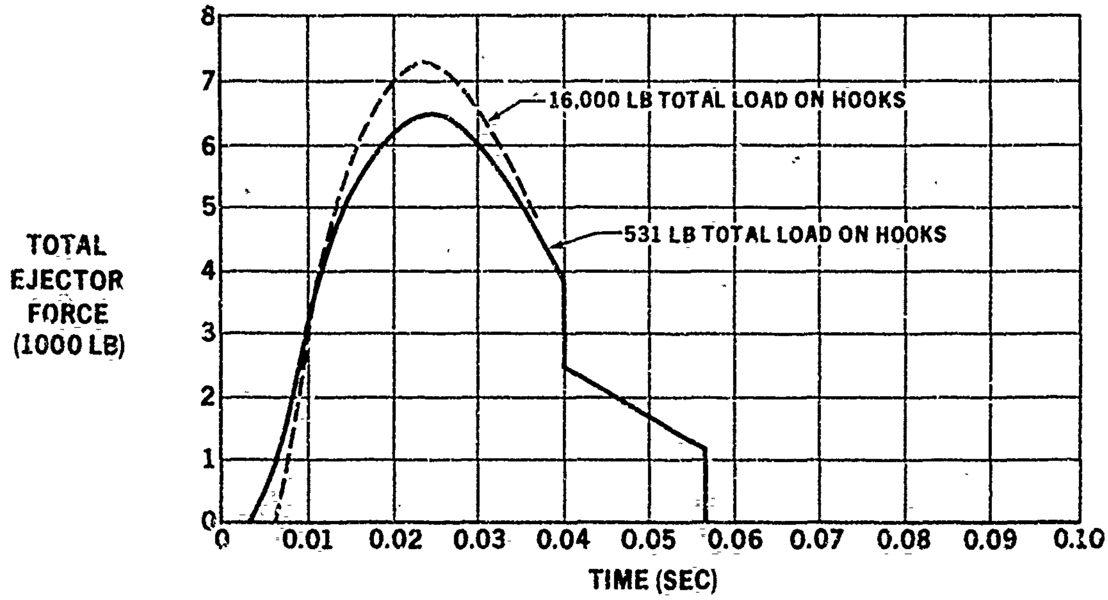

FIGURE 4. SUPER-14 HIGH HOOK LOAD EFFECT

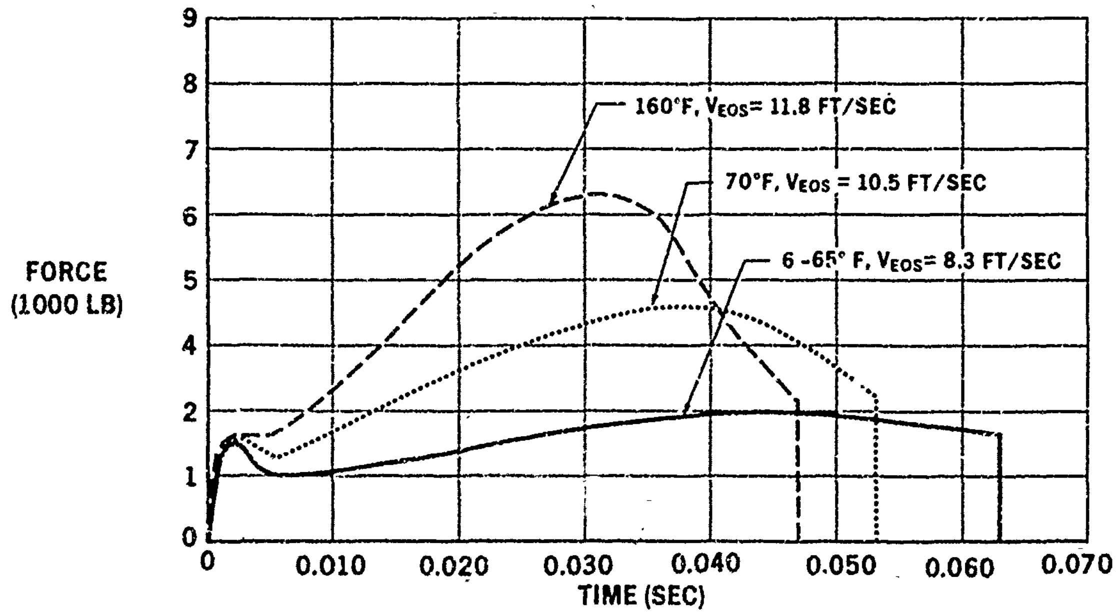

FIGURE 5. LODE-14 TEMPERATURE EFFECT WITHOUT ORIFICES

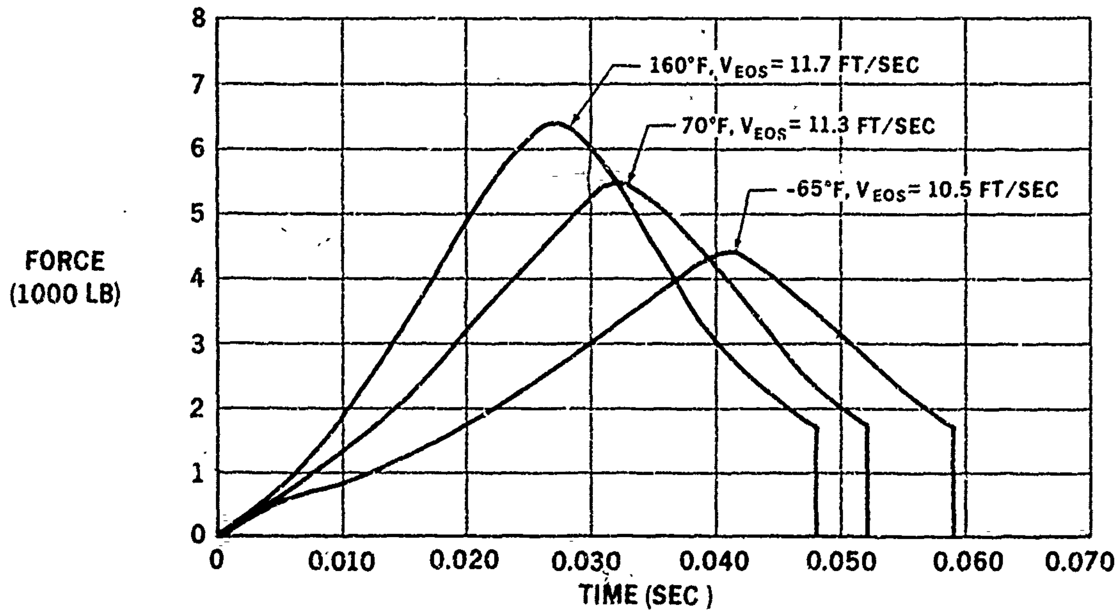

FIGURE 6. LODE-14 TEMPERATURE EFFECT WITH ORIFICES

INTERFERENCE FLOW FIELD

In reality, the aircraft interference flow field may reduce or aggravate any or all of these errors. In addition, the treatment of the self-stabilizing effect of dual ejectors and new advanced ejector concepts is difficult without taking into account the aircraft interference flow field. As a consequence, the research and development technology effort is being directed toward combining the Douglas ejector rack computer simulation with the Air Force Flow Angularity computer program. When the two computer programs are combined, the interference flow field features of the Air Force program will produce representative weapon loading so that the ejector rack operation can be simulated realistically. Through this approach, an improved general program will be obtained with which store separation and ground impact error effects can be studied for present and advanced ejector rack concepts.

INTERIM PALLETIZED CARRIAGE

Since the inception of external carriage of stores on tactical aircraft, appreciable change in combat aircraft conventional munition armament requirements has occurred. Prime requirements have evolved for increased accuracy, improved performance, and increased carriage and delivery flexibility. As a result, numerous store carriage studies have been performed to provide solutions for these needed improvements. Of these studies, the high-density bluff weapons appear to show appreciable promise. The NSRDC Star Fin bluff shape, AF BLU-58 and converted M-117M-6 are examples of current noteworthy high-density weapon developments.

BLUFF MUNITION CONSIDERATIONS

NSRDC studies of the high-density Star Fin store show considerable aerodynamic, delivery, and ballistic improvements. Through the aerodynamic improvements, increased aircraft performance in the form of increased range or speed are obtained. Delivery improvements of the NSRDC shape allow the safe separation and weapon release envelope to be expanded to increase delivery maneuver flexibility. Greater store stability during and after ejection provide ballistic improvements which result in decreased ballistic dispersion with subsequent increased accuracy.

In adopting a completely new weapon system such as new high-density munitions, considerable time is required for development and production until the weapon is available in quantity for large-scale service usage. In fact, large quantities of the new weapon will probably not be procured until the existing stockpile of conventional munitions has been reduced substantially. This delay in obtaining high-density store advantages is unfortunate. Consequently, an interim high-density store approach through conversion of existing weapons would appear beneficial.

WARHEAD REVERSAL

The reversal of the M-117 warhead and the addition of a modification kit to form the M-117M-6 is an excellent example of obtaining a high-density munition from the conversion of an existing high-quantity munition. These considerations have prompted Douglas to study the possibilities of converting the family of general purpose bombs (MK-81, MK-82, MK-83 and M-117) to NSRDC Star Fin shapes. The results of this study indicate that reasonable NSRDC shape simulation can be achieved for these bombs by reversing the warhead and adding a nose plate and star fin. In addition, the four converted general purpose bombs consist of two natural module lengths which allow easy palletization with fixed ejectors.

This high-density conversion of the MK-81, MK-82, MK-83 and M-117 bombs does not result in as high a density as the ideal NSRDC shape. However, considerable improvement over the current low-drag streamlined MK-80 series is obtained. Consequently, conversion of the existing munitions appears to offer an interim approach for palletized carriage on existing and future aircraft while retaining a sizable portion of the aerodynamic, delivery, and ballistic improvements of the ideal NSRDC shape.

MODIFIED STORE SIZING

In determining the modified store length, a matrix pallet with a fixed ejector arrangement that does not require ejection relocation for different weapon loadings is desirable. In fact, this fixed ejector compatibility is desirable for unmodified existing conventional munitions as well as the Converted High-Density MK-81, MK-82, MK-83 and M-117 stores. With these considerations as design goals, the basic high-density shapes of Figure 7 were determined. Two basic lengths are obtained: 47-inch length for the MK-81 and M-117, and 71.5-inch length for the MK-82 and MK-83. Examination of Figure 7 shows the shorter size is primarily determined by the length of the M-117 warhead, whereas the MK-83 establishes the length of the longer size.

In addition to two length sizes, the high-density warheads consist of two diameter groupings. The M-117 and MK-83 are 16 and 14 inches in diameter, respectively, and the MK-81 and MK-82 are 9 and 10.75 inches, respectively. In Figure 8, a fixed ejector repeating side-by-side arrangement is shown for the MK-81 and MK-82 high-density configurations. The two outside ejectors are utilized for the MK-83 and M-117 high-density stores. These side-by-side arrangements are also compatible with conventional multiple carriage-type munitions with the smaller stores carried three abreast and the larger stores two abreast.

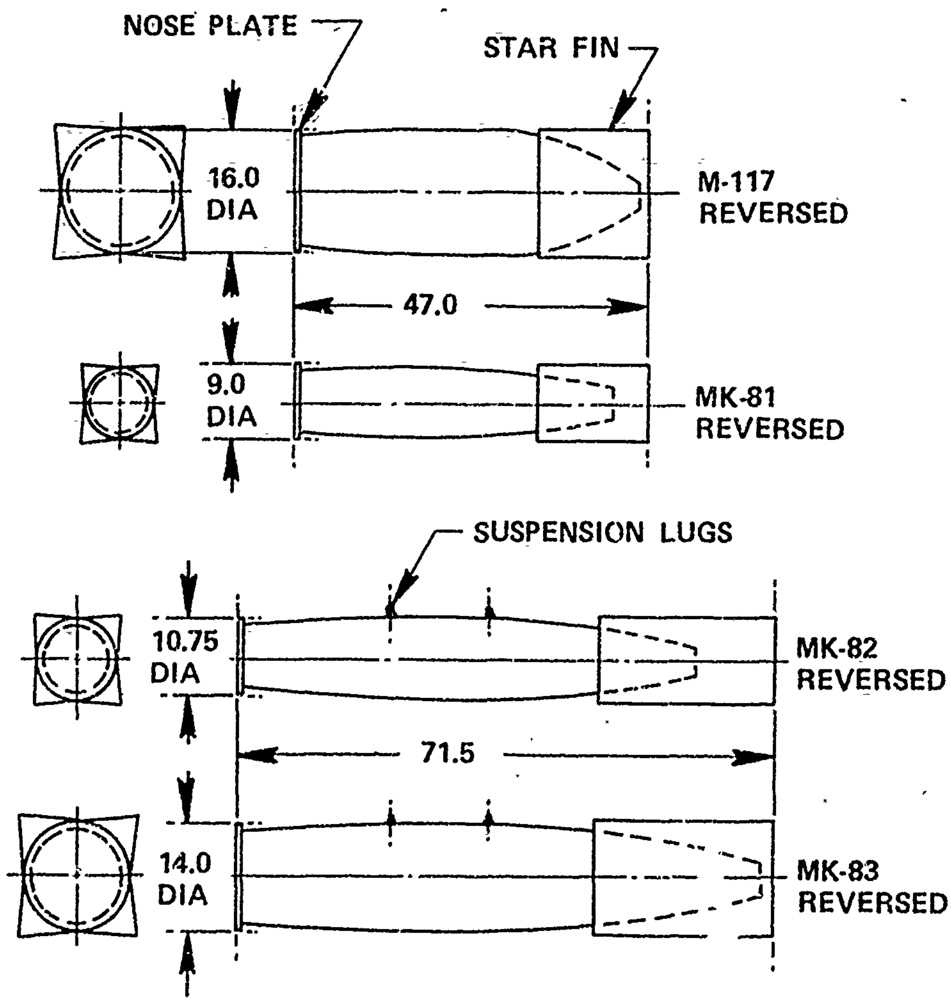

FIGURE 7. BASIC HIGH-DENSITY CONVERTED SHAPES

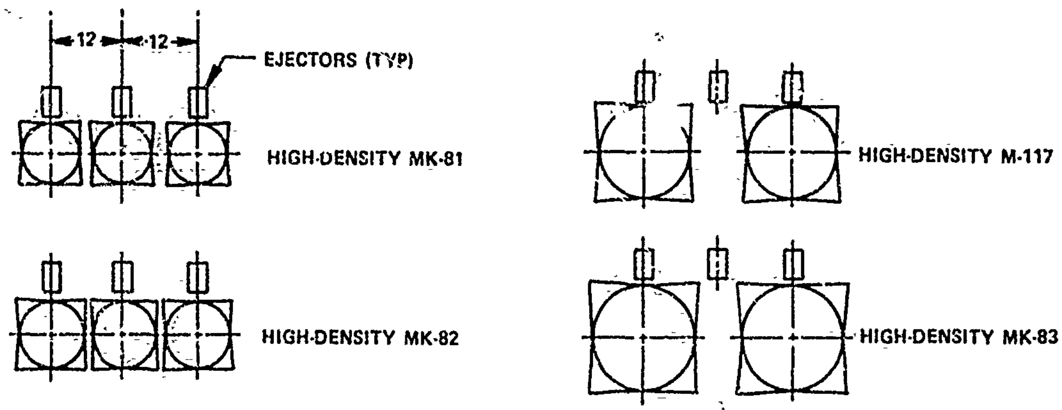

FIGURE 8. FIXED EJECTOR SIDE-BY-SIDE SPACING

CARRIAGE FLEXIBILITY

Since carriage considerations were made in determining the basic shape of the high-density converted stores, considerable carriage flexibility ca be obtained. Pallet arrangements can be designed which have fixed ejector locations compatible with high-density converted stores or the present unmodified family of multiple carriage weapons. Figures 9 and 10 show a conformal carriage arrangement for fuselage mounting and a palletized ejector arrangement for pylon mounting. Special bomb rack requirements are encountered for pallet installations such as this, especially for the center row of ejectors of the three side-by-side ejector arrangements which have very limited ground handling accessibility. Closely spaced ejector unit installations such as these are feasible with the SUPER design where conventional sway-bracing techniques are impractical.

When the converted high-density stores are carried on either fuselage conformal or pylon arrangements, a movable nose fairing is envisioned to minimize aerodynamic drag. Prior to loading of the high-density stores, this fairing is extended to fair the loaded pallet. After dropping the stores, this fairing is retracted back to fair the empty pallet. When unmodified conventional stores are carried, the fairing is not extended, and retraction is not required after releasing the stores.

INTERIM ADVANTAGES

The Converted High-Density MK-81, MK-82, and M-117 weapons carried in a palletized arrangement offer an interim approach to the conformal carriage advantages of the NSRDC Star Fin bluff weapon. A pallet arrangement is possible with these converted weapons in which a fixed matrix of bomb racks is compatible with the existing multiple carriage family of munitions as well as the converted high-density munitions. In addition, this pallet arrangement can be applied to fuselage conformal carriage, or fuselage and wing pylon applications for current aircraft with multiple carriage capability such as F-14, F-15, F-111, F-4, A-6 and A-4.

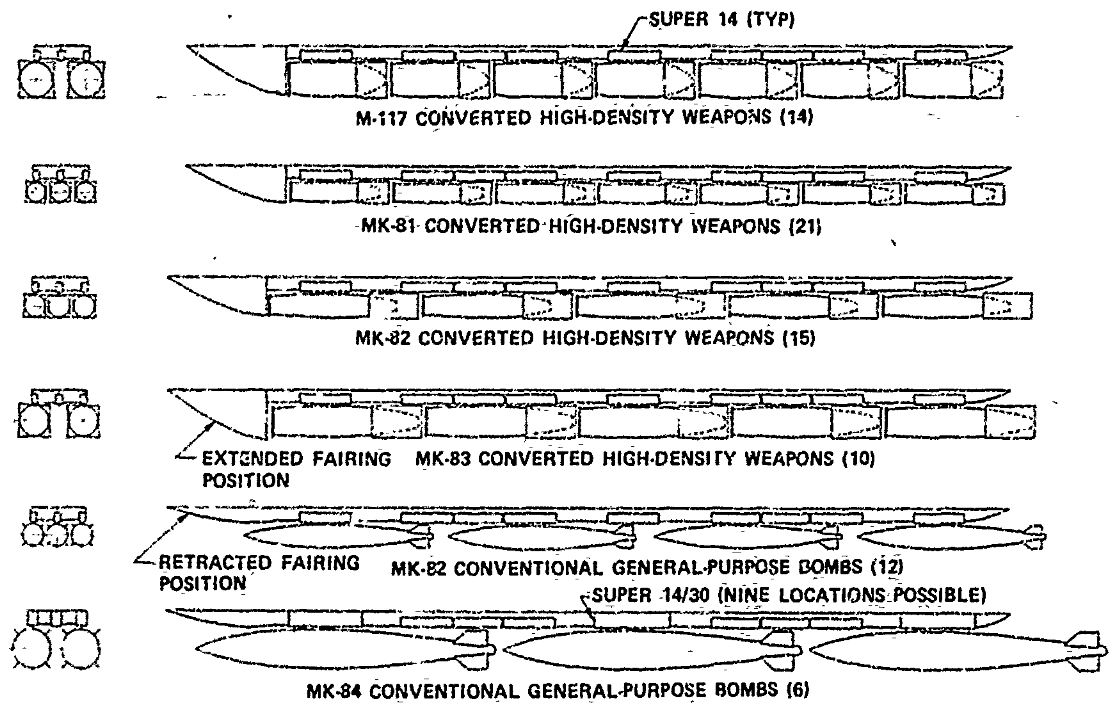

FIGURE 9. CONFORMAL CARRIAGE ARRANGEMENT

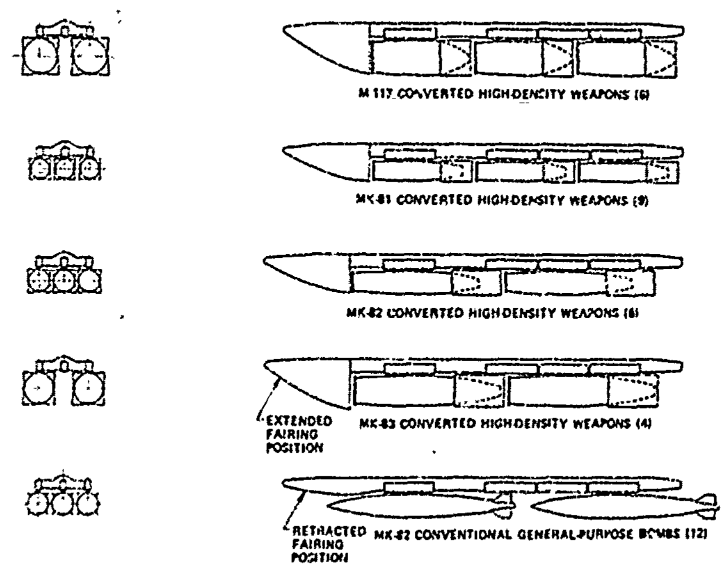

FIGURE 10. PALLETIZED EJECTOR ARRANGEMENT

With this flexible approach, an acceptable quantity of conventional unconverted munitions can be carried if the converted munitions are not available. However, if the converted high-density munitions are available, considerable improvement in combat capability can be achieved. If the length of the present bluff munitions that are in development have not been solidified to the point that change is impossible, consideration should be given to utilizing munition lengths that are compatible with the converted high-density munitions presented here. By providing this compatibility, a weapon carriage approach is obtained in which new bluff munitions, converted munitions or present conventional weapons can be used without change to the ejector rack mounting arrangement. These considerations offer a great deal toward reducing the bluff high-density weapon to a practical system for present and future aircraft conformal or pylon carriage.

SUMMARY

Through realistic computer simulation of release, ejection, store separation and ground impact, considerable expensive laboratory, wind tunnel and flight testing can be reduced. By combining the Douglas Ejector Rack Computer Program with the Air Force Flow Angularity Computer Program, an improved general model will be obtained with a potential to evaluate and improve present and advanced ejector rack concepts under multiple or conformal carriage conditions. In the development of new bluff high-density munitions, consideration should be given to selecting munition sizes that are compatible, from a carriage standpoint, with both modified converted munitions and present conventional munitions. This consideration will help reduce to practicality high-density bluff munitions that are ideal for fuselage conformal carriage or pylon palletized carriage for both present and future advanced aircraft.

AUTOBIOGRAPHY

Robert L. Kyle

Douglas Aircraft Company

Mr. Kyle received his B.S. Degree in Mechanical Engineering from Seattle University in 1962. He has since been with the Armament Group in the Mechanical Engineering Section of Douglas Aircraft Company. Mr. Kyle has been engaged in the design of armament components, low-drag store suspension equipment and armament systems analysis computer programming. He is principal investigator on Douglas Independent Research and Development (IRAD) programs concerning weapon suspension equipment improvements and advanced design concepts. Mr. Kyle is a member of the American Ordnance Association.

DIRECT SIDEFORCE CONTROL FOR IMPROVED WEAPON DELIVERY ACCURACY

(U)

(Article UNCLASSIFIED)

E. F. Carlson

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DIRECT SIDEFORCE CONTROL FOR IMPROVED WEAPON DELIVERY ACCURACY[1]
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(Article UNCLASSIFIED)

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ABSTRACT. (U) A Direct Sideforce Control (DSFC) system has been developed to improve aircraft agility and weapon delivery accuracy. One type of DSFC system uses a dedicated aerodynamic control surface mounted under the nose of the aircraft in conjunction with the rudder to balance out yawing moments. Together, these two control surfaces can produce a lateral acceleration of about 1 g for typical tactical combat aircraft. The effectiveness of the DSFC for the air-to-ground weapon delivery task has been evaluated in piloted simulation studies. This has shown that the DSFC can reduce the weapon miss distance by a factor of three over that for a conventional control system. This improvement is derived from two principal features of the DSFC. First, the pilot can make rapid, precise heading changes while maintaining a wings level attitude and zero sideslip. Second, the DSFC can be used to trim out crosswinds. This can be done while maintaining a wings level attitude with the body axis aligned with the ground track. The physiological effects of aircraft accelerations were evaluated on the NASA Ames FSAA large amplitude moving base simulator. Particular emphasis was placed on pilot opinion of the DSFC mechanization, pilot workload, and the effects of the lateral accelerations which can be generated by the DSFC.

[1]Sponsored by the Office of Naval Research under Contract N00014-72-C-0207, "An Investigation of the Potential Benefits of Direct Sideforce Control from a Mission Viewpoint," Boeing Rept. No. D180-17508-1, July 1973.

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LIST OF FIGURES

INTRODUCTION

Superior aircraft maneuverability and agility can be of decisive importance for tactical combat aircraft. The pilot's ability to precisely position his aircraft in space can be critical in such tasks as air-to-ground weapons delivery, air-to-air combat, inflight refueling, and landing under foul weather conditions. Increased maneuverability will also improve the groundfire and missile avoidance capability, as well as helping the pilot to outmaneuver and gain the advantage over an attacking aircraft.

The preceeding maneuverability requirements are strongly influenced by the aircraft lateral-directional response characteristics since each of the preceeding tasks is strongly dependent on a heading change capability. In a conventional aircraft, the pilot changes heading by first commanding roll rate. The pilot maintains this roll rate until he has established the desired bank angle. This orients the lift force developed by the wing such that the aircraft develops a heading change rate. As the desired heading is approached, the pilot commands the necessary roll rate to return to a wings level flight attitude. While this technique has been used throughout the history of aviation, it does not represent the most desirable method for changing heading. It requires considerable pilot skill to orient the aircraft precisely. Also, the time required to bank the aircraft introduces a significant time lag in the heading change maneuver. As the pilot attempts to speed up the maneuver, he will introduce large oscillations and will experience a significant reduction in the precision with which he can control the aircraft flight path and heading. This is particularly noticeable in air-to-ground weapons delivery.

A Direct Sideforce Control (DSFC) system has been developed to provide a significant improvement in the aircraft lateral-directional maneuverability and handling qualities. The DSFC uses aerodynamic control surfaces to generate a sideforce. This sideforce enables the aircraft to turn while maintaining a wings level attitude, without sideslipping the aircraft. This enables the pilot to make much more precise and more rapid heading changes than is possible with the conventional control system. With the DSFC, the pilot commands the heading rate directly. There is no need to roll the aircraft or otherwise disturb the established flight path. The DSFC also permits the aircraft to be flown in a steady crosswind by sideslipping the aircraft while maintaining wings level and a fixed heading at all times. The benefits to be gained from this new flight control system have been evaluated by pilots in a simulated dive bombing task.

MECHANIZATION

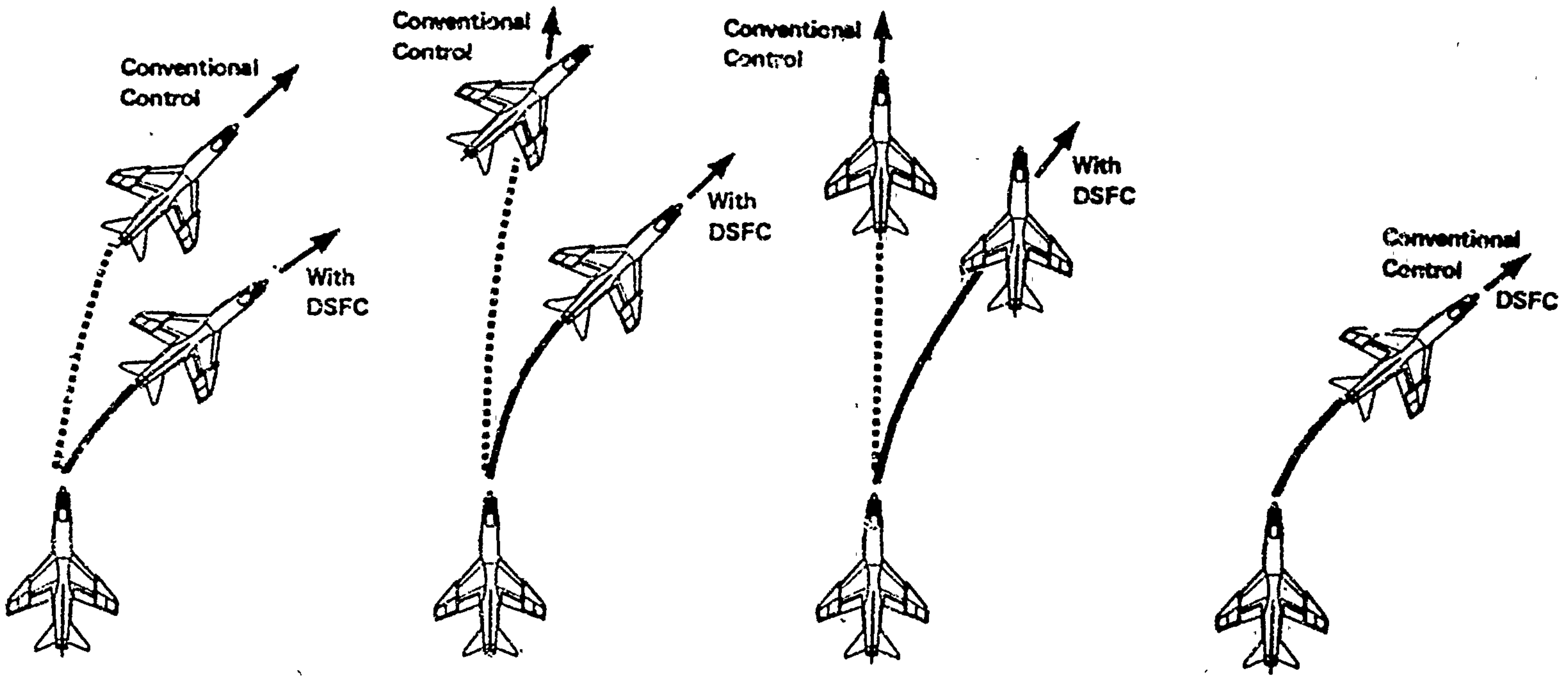
The mechanization of the DSFC has been divided into three categories: 1) operation; 2) sideforce generators; and 3) flight control system.

OPERATION

The various techniques with which the pilot can control the aircraft with DSFC are summarized in Figure 1. The various control techniques shown in this figure are identified as separate modes for convenience. They are not separately switched or keyed functions. Any or all of the control modes are available to the pilot simply by making inputs to the appropriate control, i.e., the stick, rudder pedals, or the throttle mounted controller. The pilots control inputs to the DSFC are fed directly into a small onboard computer. This computer generates the commands to drive the aerodynamic control surfaces to produce the commanded aircraft motions. This gives the proper synchronization of the control surfaces to produce a pure, uncoupled motion of the aircraft. This decoupled system gives the pilot control over the various aircraft degrees of freedom without exciting extraneous, unwanted aircraft dynamics. For example, with the Mode II control the pilot deflects the rudder pedals to change heading without inducing unwanted responses such as rolling or pitching of the aircraft. Pilot comments from this and other DSFC studies have shown that this uncoupled motion is necessary to realize the full potential of the DSFC.

SIDEFORCE GENERATORS

A series of design concepts for generating sideforce have been evaluated. First, consider that the sideforce can be generated by either aerodynamic control devices or by a form of vectored thrust. The vectored thrust system would require that the thrust be deflected a full 90 degrees to give the desired 1 g lateral acceleration on an aircraft with a thrust to weight ratio of one. Thus, it becomes apparent that the use of aerodynamic control devices is the more desirable method for generating sideforce. The most effective system is shown in Figure 2. The aerodynamic sideforces are produced by a conventional rudder used in conjunction with the chin mounted tandem sideforce generators. The rudder and sideforce generators deflect together such that they each generate about one half of the total sideforce. This results in both controls reaching approximately full deflection in response to a full input command from the pilot. This full utilization of the rudder and sideforce generators minimizes the size of the sideforce generators,



Mode I

- Operated Like Conventional Roll Control
- Speeds Up Heading Changes by a Factor of Two
- Increased Maneuverability
- Equivalent to Simultaneous Use of Modes II and IV

Mode II

- Operated Through Rudder Control
- Changes Heading, Zero Bank Zero Sideslip
- Vernier Aiming and Precision Tracking

Mode III

- Operated Through Throttle Mounted Controller
- Sidestep with Zero Bank Zero Heading Change
- Trim Out Crosswind or Sidestep Maneuver

Mode IV

- Operated with Lateral Stick
- Provides Coordinated Turn
- Used for Large Heading Changes

Figure 1: Modes of Operation

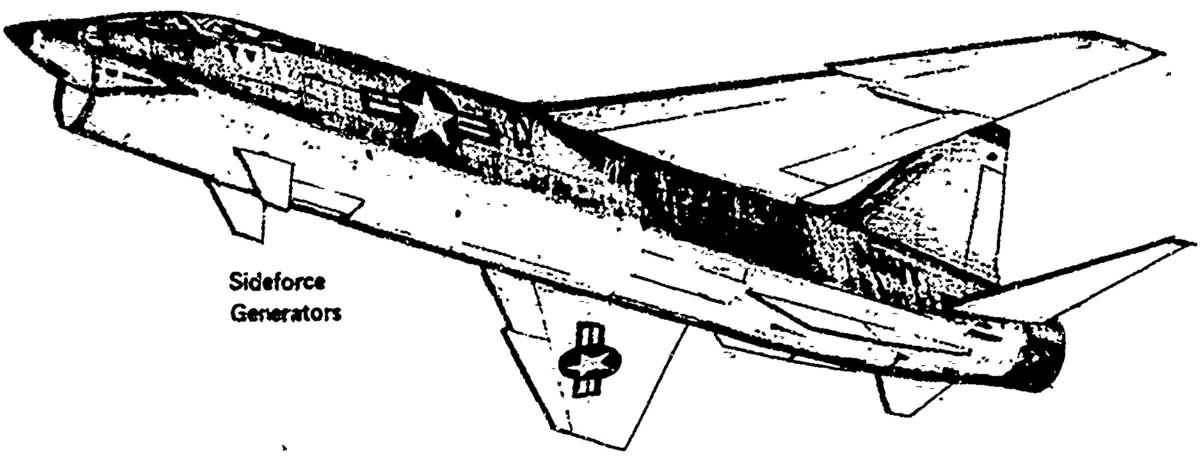


Figure 2: Chin Mounted SideForce Generator

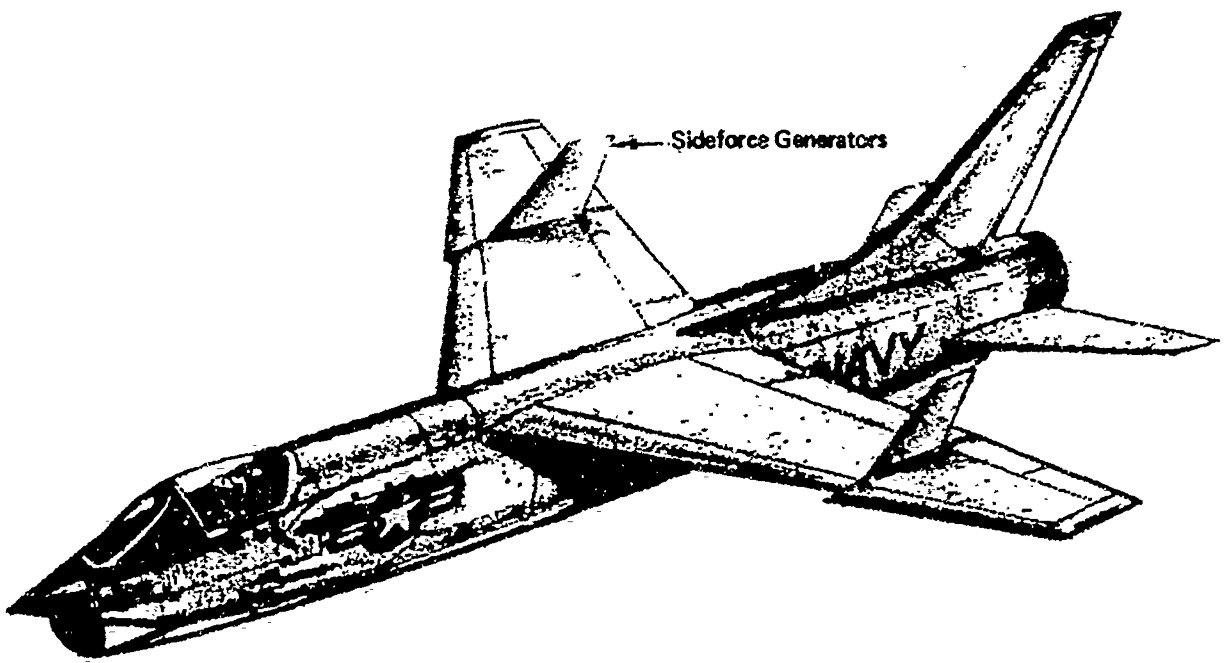


Figure 3: Wing Mounted SideForce Generator

thereby minimizing the structural weight. The location of the rudder and sideforce generators relative to the center of gravity is such that only very small yawing and rolling moments are produced when generating the sideforces. The DSFC computer automatically commands small deflections of the aerodynamic control surfaces to cancel these moments. The chin mounted sideforce generators shown in Figure 2 offer adequate ground clearance for ground based operations. These sideforce generators would, however, be subject to occasional damage in carrier operations. The sideforce generators shown in Figure 3 are positioned to avoid damage in carrier operations. The wing mounted sideforce generators will be about twice the size of the chin mounted generators since the rudder will produce only a small portion of the total sideforce.

FLIGHT CONTROL SYSTEMS

A schematic of the DSFC flight control system is shown in Figure 4. A digital computer will be used to perform the functions shown in this block diagram. Some of the more significant features of this control system will now be considered. The central portion of the control system is the decoupling network -- shown in Figure 4 as the constants C_{11} through C_{33}. This decoupling network accomplishes the following functions:

- Pilot inputs command coordinated deflections of all control surfaces to counteract the inherent aerodynamic cross coupling.

- Commands to the rudder from the side translation controller to counteract the yawing moment due to sideslip.

- Commands to the sideforce generator from the rudder pedals to provide the side acceleration required to yaw at zero sideslip.

- Commands to the aileron to neutralize the rolling moments due to sideslip and rate of yaw.

- Commands to the rudder and sideforce generator from bank angle to coordinate the turn.

With this flight control system, the aircraft responses to pilot control inputs are first order lags with no trace of excitation of the poorly damped dutch roll mode. The dutch roll is, however, excited by external disturbances. To improve dutch roll damping, the decoupled system

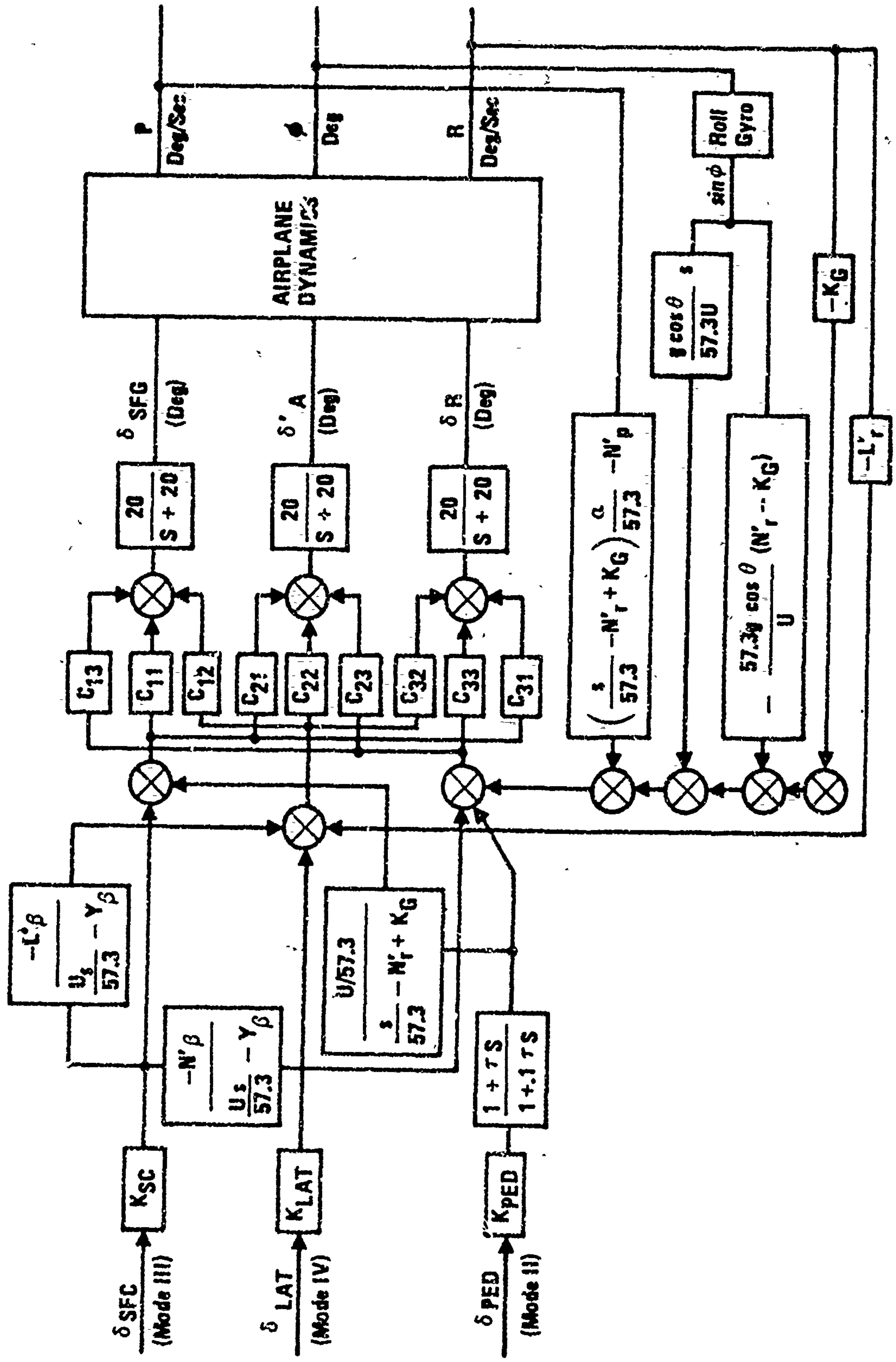


Figure 4: DSFC System Block Diagram

incorporates yawing moment feedback, K_G, proportional to measured yaw rate, as shown in Figure 4. The only effect of this feedback on the decoupled system response to pilot inputs is to speed up the heading response and reduce its magnitude. The response to a gust disturbance is, however, significantly improved by the increase in dutch roll damping.

Each of the feedforward elements shown in Figure 4 has a separate function. The feedforward from the Mode III control input to the aileron (the term with L'_β in the numerator) will be discussed first. This feedforward cancels the rolling moment due to the sideslip which is generated by the Mode III control. Alternately, this could be cancelled by a feedback of sideslip angle to aileron. This sideslip feedback has the disadvantage of increasing the aircraft response to turbulence. The second feedforward from Mode III provides a command to the rudder. This command is necessary to give a pure side translation - or sideslip - without producing a heading change. The remaining feedforward element provides a command from Mode II to the sideforce generator. This feedforward provides the command required to achieve a wings level turn at zero sideslip.

All required gain scheduling will be done within the DSFC digital computer. This gain scheduling will extend the desired flight characteristics, shown in Figure 1, throughout the flight envelope.

FLIGHT SIMULATION

The capabilities of the DSFC system for the dive bombing task were evaluated on the NASA Ames Flight Simulator for Advanced Aircraft (FSAA) shown in Figure 5. A total of 383 dive bombing runs were flown by 6 pilots on this large amplitude six degree of freedom moving base simulator. Dive bombing accuracy as well as the effects of motion were evaluated.

WEAPON DELIVERY ACCURACY

The dive bombing task, depicted in Figure 6, was used in the evaluation of the DSFC. The ground attack runs were started from 8,000 ft. altitude in a 30 degree dive. Various lateral offsets and crosswind conditions were evaluated in the simulation. The pilot's task was to line up on target such that he could obtain the best hit possible with a conventional iron bomb. The fixed depressed reticle sight used in the simulation was set for a weapon drop at 3,000 ft. and 556 kts. (M=0.85) in a 30 degree dive. The primary objective of the test on the FSAA moving base simulator was to assess

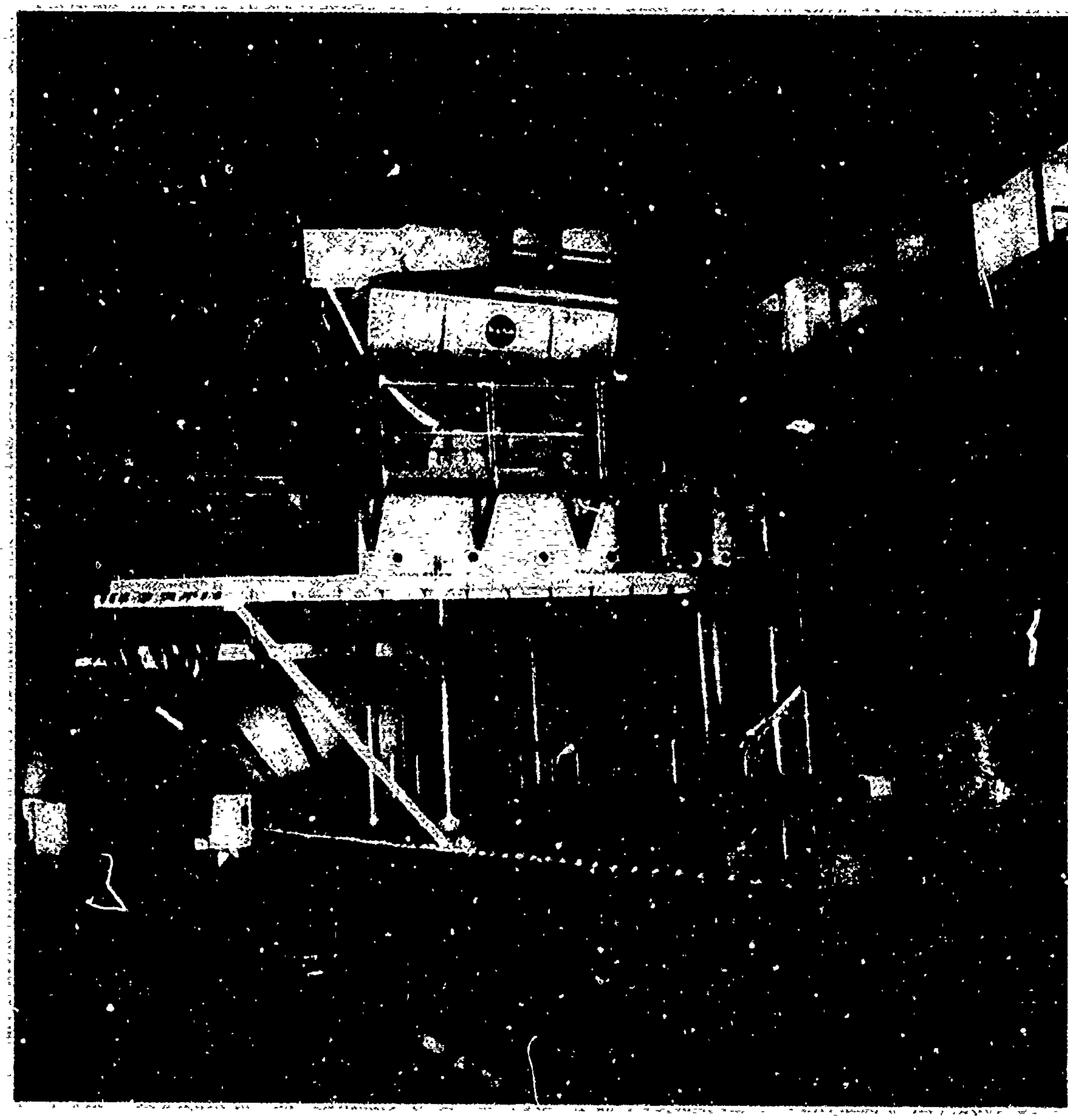


Figure 5: FSAA Moving Base Simulator

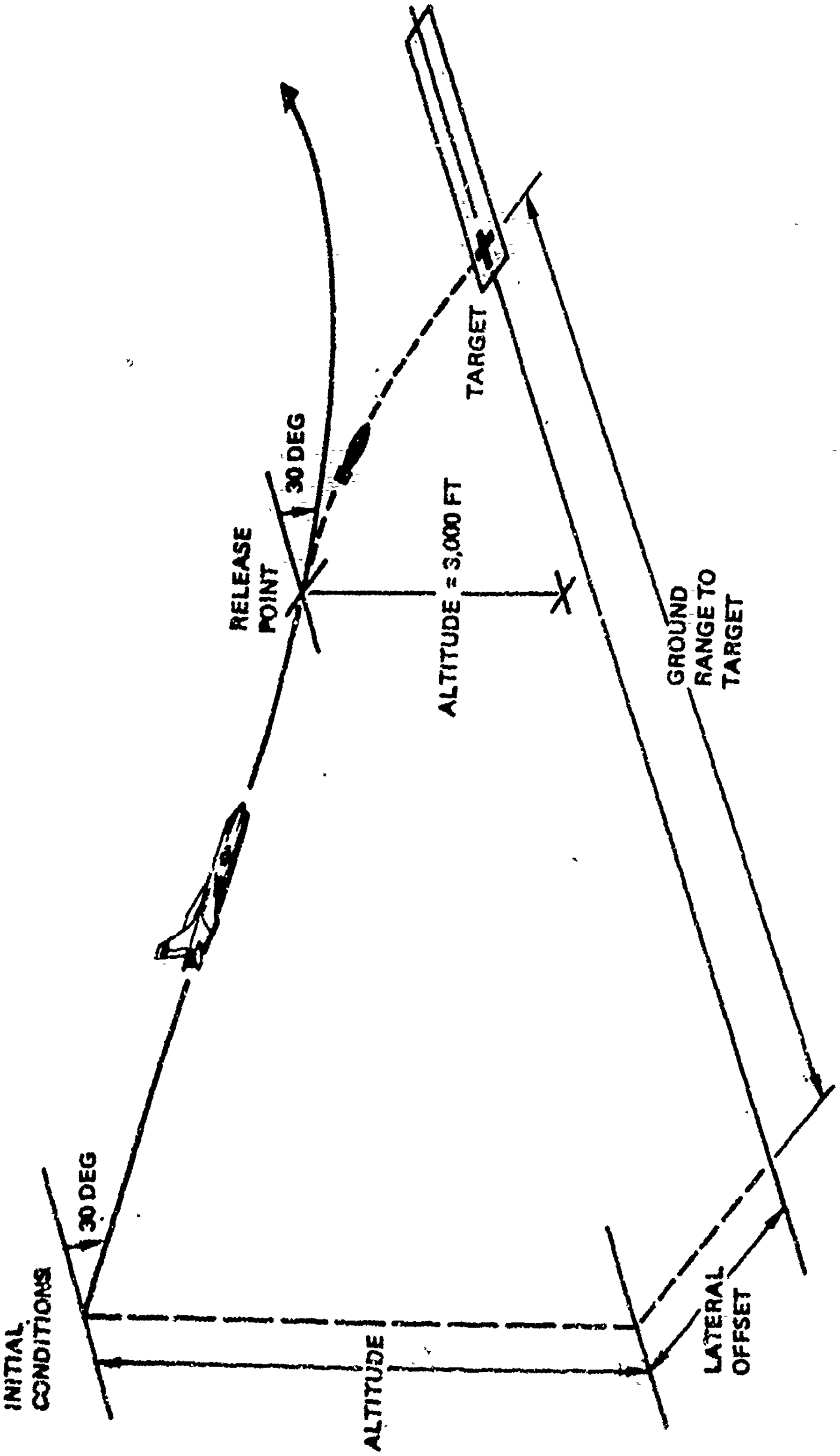


Figure 6: Typical Simulation Attack Sequence

the pilot's reactions to the relatively high lateral accelerations that can be generated by the DSFC system. To accomplish this primary objective it was determined that a total of six pilots should be used in the evaluation process. The pilot reactions and comments are discussed in the next section.

When compared with the weapon delivery accuracy for the conventional aircraft, the use of DSFC can provide significant improvements as shown in Figure 7. These data show significant increases in weapon delivery accuracy for the composite of all pilots, as well as the results for pilot A. Pilot A had the most experience and the greatest number of simulated flights with the DSFC. Some of this experience was obtained during the simulator checkout phase. As a consequence of this slightly greater experience with the DSFC he was able to improve his weapon delivery accuracy by a factor of about 3.4. When using the conventional control system for bombing, pilot A achieved slightly better than average weapon delivery accuracy. The other pilots were given adequate time to familiarize themselves with the DSFC and its operation, but the available test time did not allow them to achieve the proficiency of pilot A. This is not to say that a great deal of pilot training time will be required with the DSFC. The pilots who flew the simulation felt that the DSFC system was quite simple to use. The reduction in pilot workload with the DSFC will, in all likelyhood, result in a reduction in pilot training requirements.

Five of the six evaluation pilots were highly experienced (between 1500 and 4000 hrs. in jets) with considerable experience in dive bombing. Four of these pilots had been through test pilots school. The background of these pilots tends to bias the results toward the conventional control system since these pilots were all well trained in this type of weapon delivery. The sixth pilot, F, was selected for the evaluation program because of his low experience level (300 hrs. in jets). He had, however, done some dive bombing. The improvements in weapon delivery accuracy he was able to achieve with the DSFC are shown in Figure 8. These data show that he was able to improve his weapon delivery accuracy in the crosswind by nearly a factor of 2 when using the DSFC.

Use of the relatively shallow 30 degree dive angle in the simulation tends to bias the results in favor of the conventional control system. As shown in Figure 9 larger bank angles are required to produce the same heading change rate as the dive angle increases. The heading change rate available with the DSFC Mode II is independent of the dive angle.

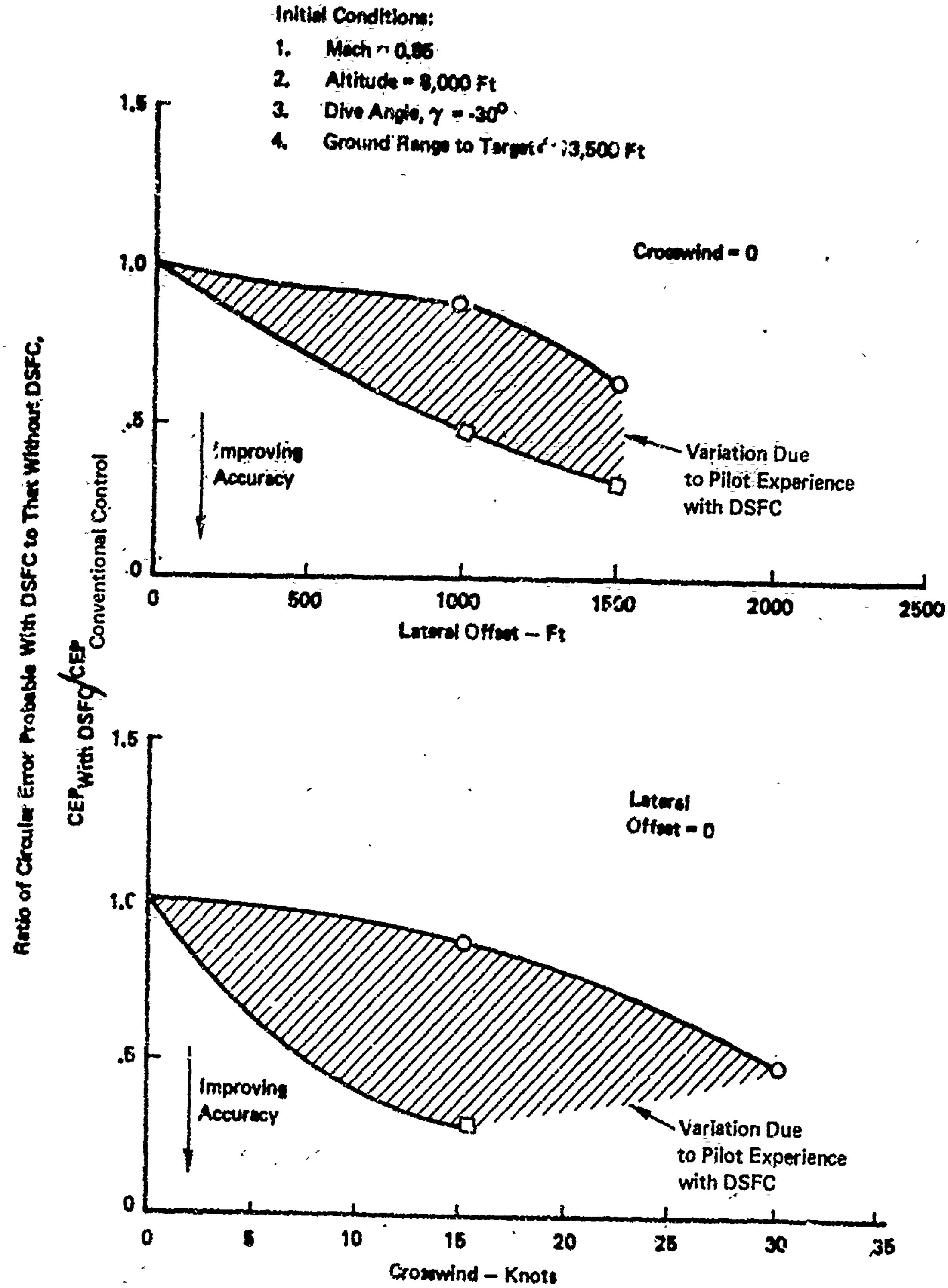
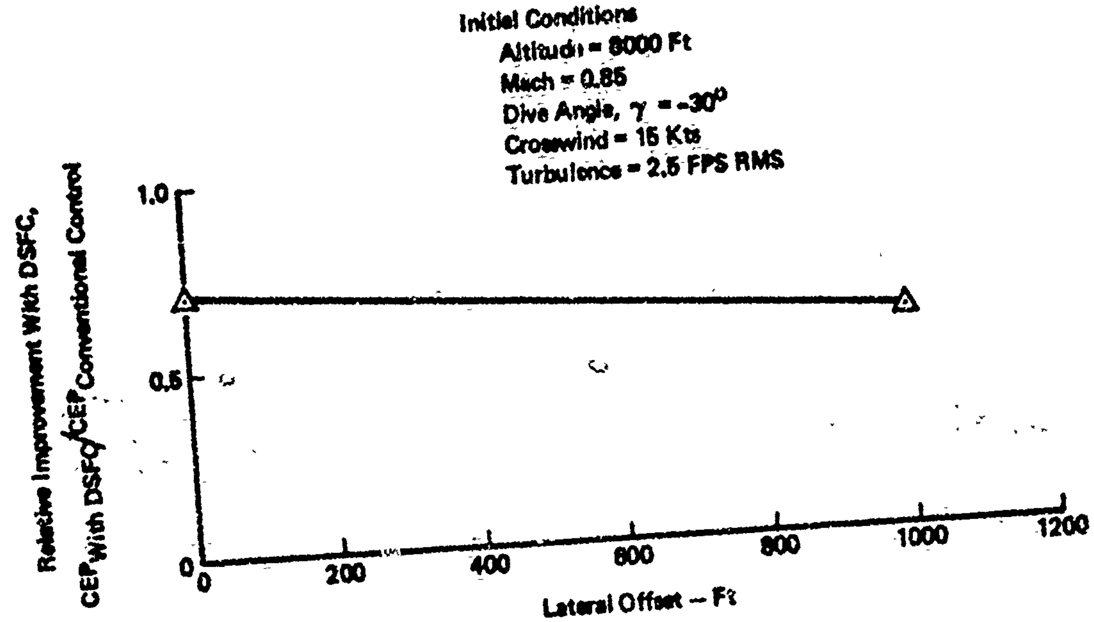


Figure 7: Improved Bombing Accuracy With DSFC



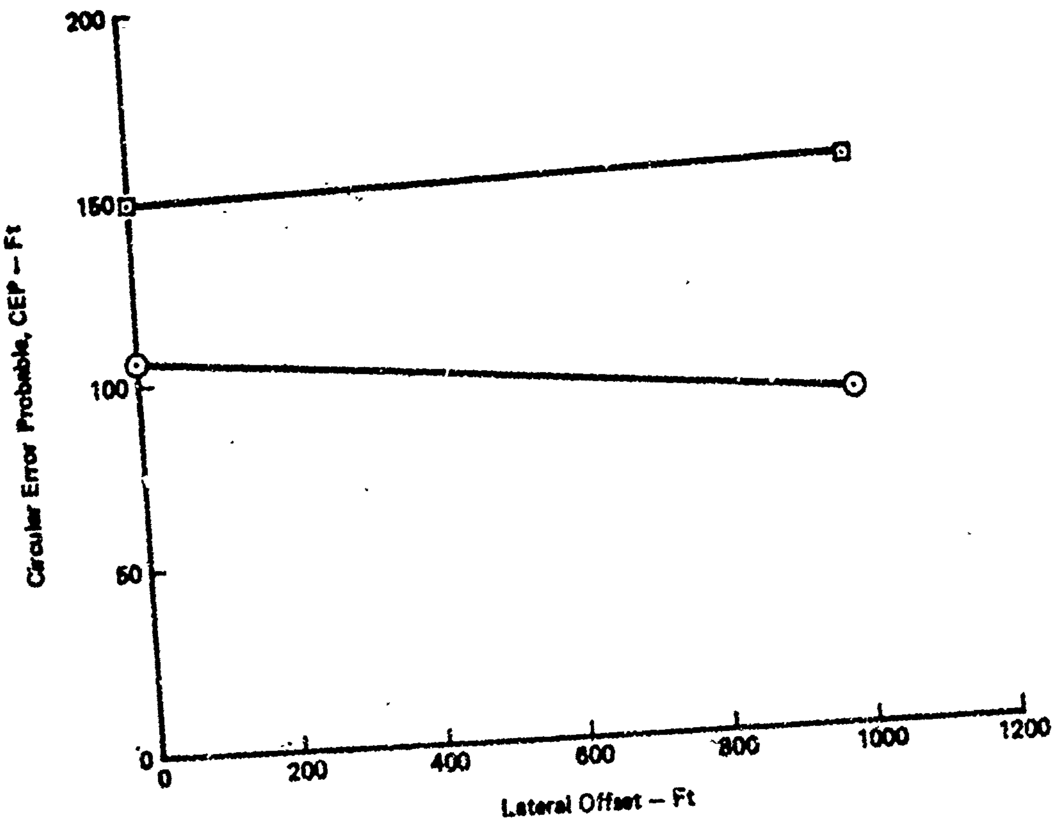


Figure 8: Dive Bombing With Offset and Crosswind — Pilot F

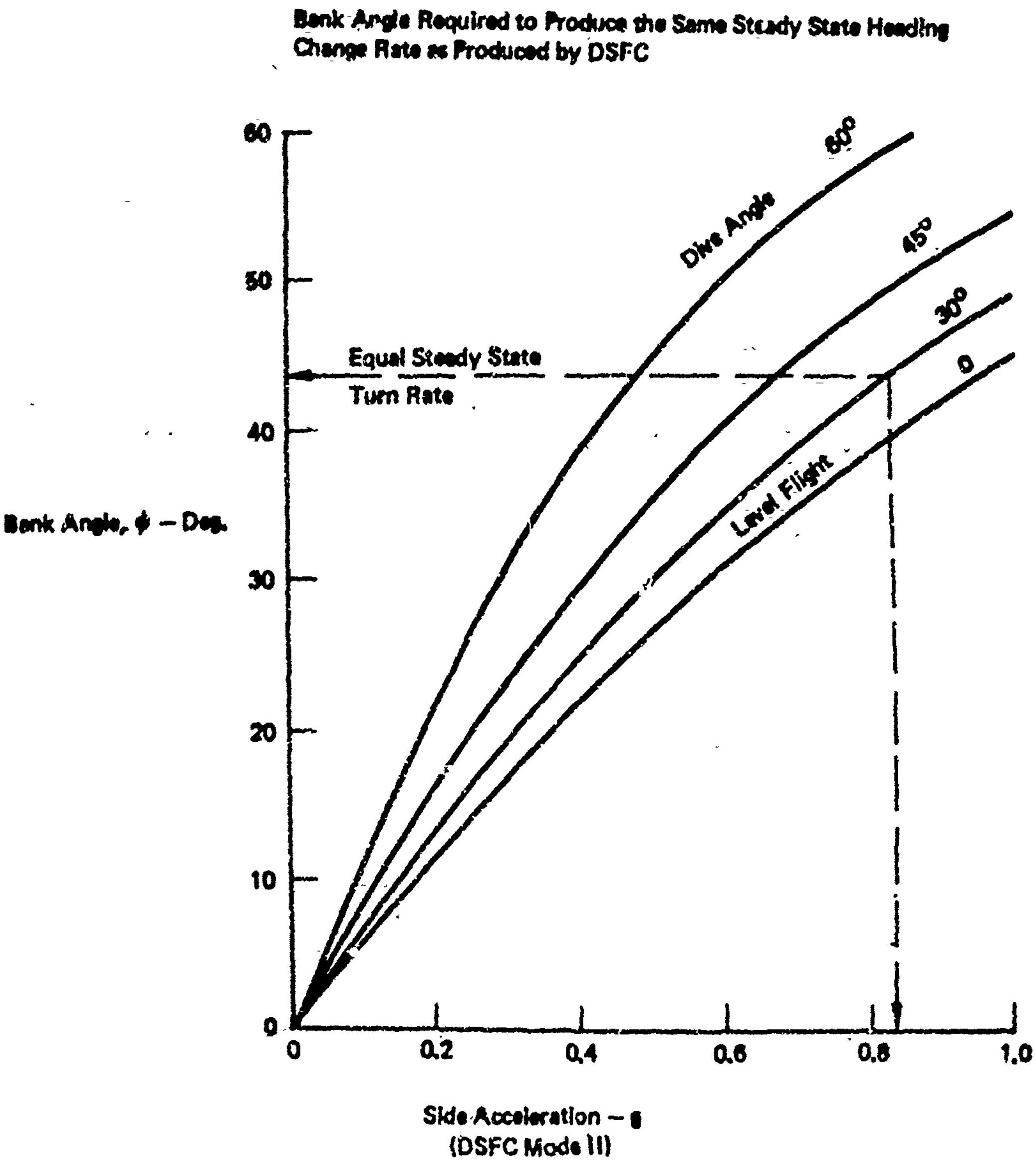


Figure 9: Comparison of Heading Change Techniques

The data in Figure 9 show that a bank angle of about 45 degrees is required to give the same steady state turn rate as is produced by the DSFC generating 0.83 g's laterally. These values are typical for the dive bombing task flown on the simulator.

While a fixed depressed reticle sight was used for this study, the results are believed to be indicative of the improvements which can be realized when using DSFC with a computing bombsight. The 556 kt. weapon release speed required a reticle depression angle of only 4.6 degrees; thus, the pendulum effect associated with this type of sight was relatively small. For an aircraft equipped with a computing bombsight the DSFC will make it possible for the pilot to follow the steering commands from the bombsight in a simpler, more rapid and precise manner than is possible using conventional control techniques. Thus, the pilot using DSFC with a computing bombsight should be able to improve his weapon delivery accuracy by about the same factor as has been demonstrated with the fixed reticle sight.

PILOT COMMENTS

The pilots who flew the DSFC simulation on the FSAA felt that use of the DSFC significantly reduced their workload. The pilots also stated that operation of the DSFC was convenient and natural.

One of the primary objectives of the test on the FSAA was to assess the effects of lateral acceleration on the pilot. To do this it was necessary for the six evaluation pilots to extrapolate the lateral acceleration forces from the 0.37 g's (FSAA maximum capability) they experienced in the FSAA simulator to the full 1 g level which the DSFC can generate on typical tactical combat aircraft. The pilots extrapolated over this range of lateral acceleration to predict that the pilot would not be adversely affected by these 1 g side loads, nor would these side loads deter him from making maximum inputs to the DSFC. The FSAA motion drive system was scaled such that the FSAA accelerated laterally with 0.37 g's when the calculated value with the DSFC was 0.85 g's. The FSAA acceleration was proportionately less for smaller DSFC commands. This scaling gave smooth, full range dynamic responses without hitting the limits of the FSAA motion drives. When the pilot would command a large, continuous linear lateral acceleration with the DSFC then the FSAA cab would accelerate in that direction, thereby causing the pilot to experience the proper acceleration cues.

For sustained DSFC inputs cab tilt was employed such that the linear lateral acceleration could be washed out before the FSAA exceeded its lateral travel limits. The pilots were unaware of the washout. They felt only a consistent lateral acceleration.

No special restraints were needed in the simulation on the FSAA. The pilot's seat in the FSAA came from a Boeing 747. The general concensus of opinion was that a contoured seat to give some side support would be desirable in an aircraft where the DSFC could produce 1 g. It was observed that when subjected to high lateral g's, the pilot might make small inadvertent adverse roll inputs through the stick. This would simply be due to the acceleration forces acting on his arm. Five out of the six pilots felt that the pilot would brace his arm and react to the acceleration such that he would not make unintentional control inputs. The possibility for spurious control inputs due to lateral acceleration would, however, be eliminated with a side-arm controller arrangement to replace the standard center stick. A side-arm controller would permit use of a simple arm rest to restrain undesired lateral arm movements which could produce a control input.

CONCLUSIONS

A Direct Sideforce Control (DSFC) system has been developed and evaluated for tactical combat aircraft. The following conclusions have been drawn from these investigations.

1) The use of DSFC for weapon delivery can significantly improve the pilots capability to line up on target and overcome the effects of crosswinds. The simulation results for a dive bombing task show that weapon delivery accuracy can be improved by a factor of 3.4 over that achieved with a conventional control system.

2) The six pilots who flew the DSFC system on the FSAA moving base simulator felt that the lateral accelerations that can be developed by the DSFC (up to 1 g) would not pose significant problems for the pilot. They felt that he would quickly become accustomed to these acceleration levels, and make full use of the DSFC system.

3) Use of the DSFC for dive bombing reduced the pilots workload significantly. The simpler, more precise type of control with DSFC should make it possible to reduce the amount of pilot training required for weapon delivery and other tasks requiring high maneuverability and/or precise alignment.

4) Use of DSFC increased aircraft maneuverability significantly. Precision heading changes of less than 10 degrees can be speeded up by a factor of 2 when compared with conventional control techniques. This can be a decisive advantage in a hostile environment. For instance, the pilot can continue jinking to a lower altitude and still hit his target in a ground attack mission. The DSFC also gives the pilot a distinct edge over his opponent in air-to-air combat.

5) A "decoupled" flight control system was designed for the DSFC. This "decoupling" eliminates the typical aerodynamic and inertial coupling effects such as the roll and sideslip normally associated with a heading change maneuver. Pilots who flew the DSFC simulation stated that this decoupling was necessary for effective use of the DSFC. The DSFC flight control system design which has been developed also tends to minimize the aircraft response to atmospheric turbulence.

AUTOBIOGRAPHY

E. FRANK CARLSON - Senior Engineer
BSAA, University of Colorado, 1964
MSAE, University of Washington, 1969

After joining The Boeing Company in 1965, Mr. Carlson was given responsibility for the stability and control analysis of various preliminary design efforts on fighters, bombers, and transport aircraft. During his assignment on the Supersonic Transport Program, Mr. Carlson's primary responsibility involved the development of the piloted handling qualities simulation system which was then used in establishing SST design criteria. This simulation involved a sophisticated modeling of the nonlinear aerodynamic and aeroelastic characteristics as well as flight control systems. Mr. Carlson served as principal investigator on the contract with the Office of Naval Research to evaluate the feasibility of improving fighter/attack aircraft agility through the use of a direct sideforce control system.

Prior to joining The Boeing Company, Mr. Carlson was engaged in the development of the FB-111 and RF-111 at General Dynamics, Fort Worth.

THE CONFORMAL CARRIAGE JOINT SERVICE
DEVELOPMENT PROGRAM
(U)
(Article UNCLASSIFIED)

by

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ABSTRACT. (U) The Navy and the Air Force have developed a Conformal Carriage system by means of an extensive analytical/wind tunnel/flight test program. The wind tunnel results have been thoroughly confirmed by a flight demonstration vehicle. All results have shown the gains in aircraft performance and weapon separation by using fuselage tangential mounting of both conventional and advanced bluff-weapons.

The Naval Ship Research and Development Center (NSRDC) has been studying optimum mounting arrangements of conventional and advanced bluff weapons for a number of years. The conformal concept evolved from these aerodynamic investigations which have confirmed the hypothesis that the high density package can be stabilized and that this and other more conventional types of weapons can be carried very efficiently tangent to the aircraft fuselage. In 1971, the Air Force Armament Laboratory (AFAL) brought their experience and interest into the program to share the cost of a flight hardware program. Boeing was selected to provide aircraft modifications, conformal carriage hardware, and assistance in the analysis of flight test results. The flight program, designed around Navy F-4B 148371, began in May 1972 and was completed in April of 1973. The Naval Weapons Center at China Lake conducted all flight tests which included both aircraft performance and weapons separation from subsonic through supersonic speeds.

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LIST OF FIGURES

FIGURE

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INTRODUCTION

The Conformal Carriage Development Program had the objective of conducting a proof-of-concept flight demonstration of a full-scale hardware system. The Navy and the Air Force have successfully developed and demonstrated this conformal carriage system by means of an extensive analytical/wind tunnel/flight test program. The experimental results obtained in the wind tunnel have been thoroughly confirmed by the flight demonstration vehicle. All results have shown substantial gains in aircraft performance and weapon separation by using fuselage tangential mounting of both conventional and advanced bluff-conformal weapons. In fact, the flight envelope of the F-4 carrying weapons conformally nearly matches the F-4 fighter flight envelope. Furthermore, weapons can be released consistently and accurately at all speeds up to and including supersonic. A report on this program has been given at each of the two preceding Aircraft/Store Compatibility Symposiums (References 1 and 2). Also, a report on the results of the supporting bluff weapon flight program was given at the last Symposium (Reference 3).

The Naval Ship Research and Development Center (NSRDC) sponsored by the Naval Air Systems Command, has been studying optimum mounting arrangements of conventional and advanced bluff weapons for a number of years (see Reference 2). The conformal concept (Figure 1) evolved from these aerodynamic investigations, which have, over the years, generated and confirmed the hypothesis that the high density package can be stabilized and that this and other more conventional types of weapons can be carried very efficiently tangent to the aircraft fuselage. In 1971, the Air Force Armament Laboratory (AFAL) brought their experience and interest into the program to share the cost of a flight hardware program. Boeing was selected to provide aircraft modifications and conformal carriage hardware as well as to assist in analyzing the performance flight results. The flight program was designed around Navy F-4B 148371 and began in May 1972. This effort was successfully completed in April of 1973 including both aircraft performance and weapon separation at subsonic through supersonic speeds. The Naval Weapons Center at China Lake was responsible for the conduct of all flight tests and has provided analysis of the weapon separation results.

An overview of this Conformal Carriage Program is presented herein with particular attention paid to some historical background, the hardware and aircraft modifications, the supporting wind tunnel program, the overall flight program, and qualitative aircraft handling qualities. Detailed results in aircraft performance and weapon separation will be thoroughly covered in two other papers to be given at this Symposium (References 4 and 5).

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HISTORICAL BACKGROUND

The conformal carriage concept originating at the Aviation and Surface Effects Department of NSRDC was a natural outgrowth from attempts to solve the high store drag and poor store separation characteristics accompanying multiple external store carriage. These efforts were part of the store carriage/launch aerodynamics program and aircraft/store compatibility studies. Similar efforts and thoughts were had elsewhere and at the Boeing Company in particular. Captive aerodynamics and store separation advantages obtainable by using the conformal carriage concept were verified through extensive wind tunnel work at NSRDC.

Because these advantages were shown to be considerable, it was decided that a proof-of-concept flight program was warranted. After evaluating several aircraft types, an F-4 was selected as having the most promise for accomodating a good conformal carriage arrangement. This was a fortunate choice, since the Air Force indicated an interest in sharing the cost of a flight program, but with the stipulation that the Navy plans be expanded to include supersonic performance and weapon separation. The Boeing Company had been selected to translate the Navy conceptual design into a piece of installed hardware. However, with the increased flight envelope requirement a hardware redesign became necessary.

With goals now defined, the joint Navy/Air Force effort became a reality. NSRDC proceeded to accomplish an extensive wind tunnel program to quantify performance, stability, control, and weapons separation for the specific F-4/Conformal Carriage. The wind tunnels at NASA Ames and NASA Lewis were used to obtain supersonic performance and weapons separation, respectively. The specific program included the Mk-82 500 pound general purpose bomb, the Rockeye II dispenser, the M-117M6 (modified M-117) bluff weapon, and the NSRDC F.R. (fineness ratio) 3.75 900 pound advanced bluff weapon. This selection was based on being representative of both conventional and advanced bluff store types.

At about the same time Navy F-4B (Bu. No. 148371) was made available to the program through the T & E Coordinator and flight test equipment was made available, along with considerable help, through personnel at the Naval Air Test Center (NATC), Patuxent. Because of the R & D nature of the program, the Naval Weapons Center (NWC) at China Lake was chosen to conduct the performance flights. As the program progressed, NWC and their Naval Air Facility pilots also flew the weapon separation flights, including some at Edwards AFB.

Meanwhile, Boeing had begun their detailed design work which wound up as the installed conformal carriage adapter.

With the preliminary "logistics" completed, the flight program began with "baseline" flights of the F-4B with and without conventional weapons on multiple racks. The data obtained during these flights

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provided the basis for comparison of all succeeding flight data. These flights began in May 1972. Upon completion of these baseline flights, the F-4B was flown to Boeing, Seattle for the final fitting, checking, and installation of the adapter. The conformal carriage flights then commenced. Flights were completed in April 1973 with outstanding success.

HARDWARE AND AIRCRAFT MODIFICATIONS

From the very beginning, wind tunnel results had shown that, with appropriate practical considerations, the best external weapons carriage arrangement consisted of grouping the weapons as closely as possible, with a minimum frontal area, and in a single layer tangential to the aircraft fuselage. The closeness of the weapons is limited only by the need to avoid contact with each other during weapon release. Once a minimum frontal area can be established (assuming one wants to carry as many weapons as possible) lengthening the package (front to rear) adds an insignificant aerodynamic penalty. Although more than one layer of weapons can increase the number carried, the additional aerodynamic penalties and hardware complications preclude further consideration (at least until better mounting/ejection systems are developed).

It was therefore known that the desired arrangement was, at least conceptually, an externally mounted matrix of hard points/ejectors to accomodate the weapons, that is, using minimum profile racks mounted to allow fore and aft and lateral adjustment to accomodate the many different sizes and shapes of weapons. Furthermore, external sway bracing was considered undesirable. For an appropriate marriage of this weapons to aircraft interface package, the best sort of aircraft is one with the largest flat underside with a minimum of interruptions by landing gear and other such unrelocatable items.

After considering several aircraft candidates, the F-4 was chosen as the demonstrator since there are no serious interruptions over a fairly large surface area, since the aircraft has a large enough load carrying capability to allow demonstration of the full benefits of conformal carriage, and since there is some potential for further engineering development of the demonstration package to the point of providing a retrofit for operational use. Again, the F-4 was a fortunate choice since it does have the supersonic capability needed to fit the Air Force program requirements. But, so much for the concept.

The conformal carriage structure was designed around a matrix of adjustable hard points to accomodate the following weapon arrangements: twelve Mk-82 General Purpose bombs (four columns of three rows), twelve Mk-20 Mod 0 Rockeye II dispensers (four columns of three rows), nine M-117M6 bluff bombs (three columns of three rows), and nine NSRDC 3.75 bluff bombs (three columns of three rows). The M-117M6 bluff bomb consists of the M-117 warhead carried tail first with a nose cap and new stabilizer fins (see Figure 2). The NSRDC 3.75 bomb is a 14 inch diameter fineness ratio of 3.75 cylindrical 900 pound warhead with a star-fin stabilizer (see Figure 3). The ejector rack used was the McDonnell Douglas Lode 14A which uses "T lug" suspension with no external sway braces. The dual breech modification was also incorporated. A steel structural reinforcement was added to strengthen the rack since the Lode 14A was designed for side mounting on a structural strongback.

The conformal carriage adapter (shown installed in Figure 4) was then 6 inches deep, 96 inches wide, and 326 inches long including the 302 inch flat area for locating the ejector racks. There were forty nine ejector mounting positions available in seven columns and seven rows. At any one time, three rows of up to four columns could be used, depending on the weapon loading arrangement selected. Relocation of racks was accomplished by moving the cross beams. The skin panels could then be relocated as needed. This specific design was based on accomodating the selected weapons list; however, the list could have been much more extensive with no further design modifications (but not including weapons with 30 inch suspension). The structure was designed for permanent attachment to the aircraft; that is, all primary load transfer points were built in and forward and aft fairings were permanently attached. This approach was taken since the aircraft was to be stricken at the end of the program and since the demonstration was strictly proof-of-concept and as such could not represent a fully developed operational hardware item.

The Boeing Co. design included four critical design areas: attachment of the conformal carriage keel beam to the aircraft keel beam and wing box, attachment of the longerons to the aircraft body side longeron and wing box, attachment of the cross beams to the wing box, and support of the forward longerons in the aircraft forward missile wells. The main conformal carriage longerons were segmented to preclude overloading the aircraft longeron. The conformal carriage keel beam was tapered on the aft end to gradually transfer aircraft keel beam loads into it. At the forward end a tapered steel plate was attached to both keel beams to spread the major portion of the aircraft keel beam loads laterally over the wing skin at the intermediate spar. Cross beams were attached to the wing box at the wing center line rib and wing center line splice area using existing bolt holes to preclude reduction of wing skin net area. Structural bulkheads and shear plates were located in the forward missile wells to support the forward longerons.

The load factors used in design of the structure were based on MIL-A-8591D. Although no F-4 aircraft flight envelope restrictions due to structural limitations will result from conformal carriage, the test aircraft was placarded at 3.6 g vertical load with weapons (unlimited without weapons). This approach was taken to keep a high safety factor and avoid extensive structural tests.

A rather innovative approach was taken by the Boeing Co. in manufacturing the adapter to insure proper fit. The Navy provided an F-4 fuselage hulk from which Boeing made a female mold of the aircraft lower surface. This resulted in precise resolution of that surface from which a steel reinforced plastic replica was cast. This replica was then used as a base for development of full-size plaster master molds of the conformal carriage adapter external components. Plastic molds were then made either for casting low shrink concrete stretch form blocks or for use as fit gages when hand forming bulkheads and fairing skins. This procedure avoided the normal lengthly lofting process to establish mold lines and interface details. All parts were essentially custom made, some being "made to fit" during the aircraft modification process. Assembly was accomplished on the aforementioned replica (see Figure 5) using the ejectors as a spacing tool and allowing for rearrangement of cross beams and panels to establish the selected matrix of weapon loads. Detachable forward fairings for the bluff weapons were also fabricated (see Figure 6).

Modifications to the F-4B itself to accomodate the adapter were kept to a minimum for purposes of this flight demonstration. Some form of these modifications are mandatory for an operational system, although the additional changes needed to provide good service and maintenance features have been identified. That is, all maintenance and service requirements for an F-4 conformal carriage system have been tentatively resolved.

The engine oil service points were moved to the main landing gear well, and the oil lines were spliced into the existing lines in place of the quick engine change fittings. The LOX fill/vent valve was moved into the left forward missile well with tubing lines run to the LOX converter. The canopy air pressure gages were moved into the right forward missile well. The engine air start duct was extended to a point aft and outboard. The engine auxiliary air doors were replaced with a set of louvers operated by the air door actuators. These louvers were linked to flat shutters on the exterior conformal carriage adapter surface. A new weapons management system was devised and incorporated into the centerline pylon electrical circuit.

For the actual installation process, the F-4B was mounted on jacks. The preassembled conformal carriage adapter was placed on a cargo loader unit for mating to the F-4B. The entire preassembled adapter was then raised into position with only the keel beam and a few structural components already in place. A system ground test was conducted by the Navy and the F-4B was lowered onto its feet. The flight from Seattle to NWC took place on 7 July 1972.

WIND TUNNEL PROGRAM

Meanwhile, NSRDC had generated considerable data of a generalized nature in developing the conformal carriage concept. However, as a flight program began to take shape, an extensive wind tunnel program was undertaken to establish the flight and weapon separation characteristics of the specific F-4/Conformal Carriage configuration. Analysis of these data provided justification for flight clearance as well as further evidence of the potential operational benefits of the concept.

The full subsonic, transonic, supersonic flight regime of the F-4 aircraft was investigated. Subsonic and transonic work was performed in the wind tunnels at NSRDC. Supersonic performance work was conducted by a combined NSRDC, AFAL, NASA, Boeing Co. crew at NASA Ames. Supersonic weapon separation work was completed at NASA Lewis with a NSRDC/NASA crew. A noteworthy accomplishment for these separation investigations was NSRDC's development of a multiple store release capability. The device used consists of electrically controlled pyrotechnic cutters which can operate on a time delay sequence to release dynamically scaled models in the desired order. This allowed a simulation of more than one release per blowdown run as well as providing a means for simulating full-scale sequential releases.

Specific configurations included all weapons carriage configurations. Take-off and landing conditions with landing gear and flaps extended were also simulated. Subsequent analysis provided an accurate (as was later proven) assessment of the primary performance and longitudinal stability flight behavior as well as a good indication of lateral and directional behavior. This information, along with a thorough structural analysis, by the Boeing Co., provided the basis for the flight clearance by the Naval Air Systems Command. It also provided information for Boeing to make additional refinements to the adapter external shape.

Although it was not necessary to structure the wind tunnel and flight programs in such a way as to allow a complete correlation between them, some comparisons are worth mentioning. Results from the NSRDC 7 x 10 foot transonic wind tunnel showed the drag increments measured were within the accuracy range of the flight test data for the case of twelve Mk-82's on the conformal carriage. However, for the bluff weapon shapes a comparison showed superior performance demonstrated in flight than was measured in the wind tunnel. Weapon separation simulated by dynamically scaled models ejected in the wind tunnel was representative of full scale weapon separation. This included reproducing oscillations that occurred in flight.

FLIGHT PROGRAM

The flight program was developed around two major demonstrations: performance and weapon separation. In addition, stability, control and handling qualities were qualitatively evaluated in conjunction with the performance flights. Performance was evaluated using subsonic fuel mileage and supersonic acceleration flight test methods. That is, for subsonic flight, the fuel mileage was measured in stabilized flight at two constant W/δ conditions (aircraft gross weight/atmospheric pressure ratio) of 50,000 pounds and 130,000 pounds. Flying at a constant W/δ is essentially flying at a constant lift coefficient at a particular Mach number. The flight altitude for each data point is determined from the in-flight gross weight divided by the selected W/δ.

These constant W/δ's were selected as representative cruise and penetration flight conditions. Since fuel mileage measurements are at best difficult to achieve during supersonic flight, acceleration tests were performed to obtain data at supersonic speeds. These were accomplished using full afterburner, level flight accelerations from a Mach number of 0.8 to near the maximum speed possible, i.e., to the point of zero excess thrust. The excess thrust can then be computed from the acceleration time histories. An evaluation of supersonic performance can be made by comparing levels of excess thrust available for given flight conditions. Weapon separation data were obtained primarily from high speed film coverage: from on-board cameras and from a photo-chase aircraft. A few selected flights were flown on the range at Edwards AFB to provide a quantitative basis for evaluating the films. A photo panel display was arranged in the F-4 back seat to record flight and fuel conditions. Additional details of the test procedure and of the following results will be given in References 3 and 4, two other Symposium papers.

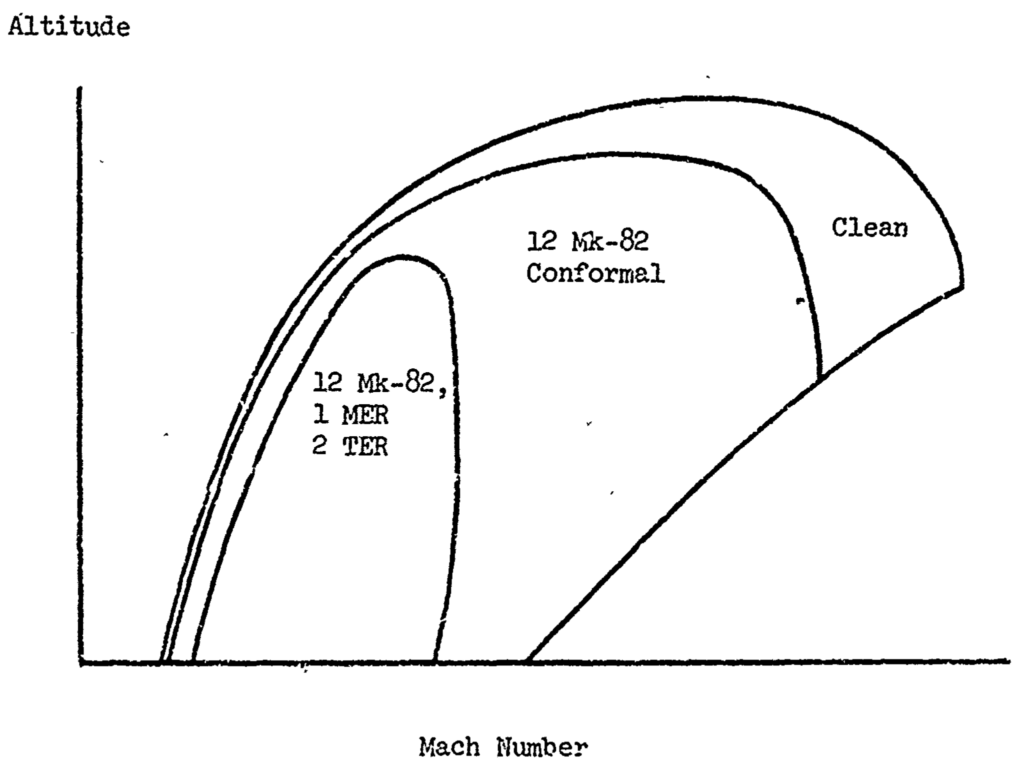
The initial series of flight tests consisted of three baseline performance evaluations which began in May 1972 at NWC. The information obtained on these flights provided a reference base for determining performance increments and allowed a direct comparison between a conventional and a conformal arrangement. The first baseline configuration flown was a completely clean F-4, i.e., no weapons, multiple racks, or parent pylons. Parent pylons were reinstalled, two Triple Ejector Racks (TER) were installed on wing pylons and one Multiple Ejector Rack (MER) was installed on the centerline pylon. This was flown as the second baseline configuration. The third baseline configuration added twelve Mk-82 GP bombs to the multiple racks. All baseline configurations were flown at both W/δ conditions. The first (clean) baseline configuration was flown for supersonic acceleration.

At this point in the program the F-4B was flown to Seattle for the installation of the conformal carriage adapter and then flown back to NWC for the remainder of the flight program.

Once the conformal carriage adapter had been installed (see Figure 4) performance flights were continued. Again, all flight conditions (both W/δ's and supersonic acceleration) were performed. The overall results indicated that the F-4B with the conformal carriage adapter in place flew as well as or better than the clean F-4B (no pylons).

The primary part of the performance flights was flown with twelve Mk-82's (Figure 7), nine NSRDC 3.75 bluffs (Figure 8) and nine M-117M6's being flown for both W/δ conditions and supersonic accelerations. Additionally, twelve Rockeye II's and a load of six Mk-82's (two columns, three rows) were flown at W/δ = 130,000 pounds.

Analysis of data from these flights has effectively substantiated the performance improvements possible through the conformal carriage of external stores. Of greatest significance is the fact that the drag has been reduced so much that it is possible to fly the F-4 supersonically with external weapons nearly to the full extent of the flight envelope of the clean F-4, as represented in the sketch below.



Store separation flight testing began at NWC in March 1973. High speed cameras were carried two each in two wing mounted camera pods and one on the aircraft nose for the separation tests (see Figure 9). Single release and ripple salvos were successfully demonstrated for all four weapon types over the full flight range in both level flight and dives. One exception to this was the NSRDC 3.75 bluff weapon which, although showing superior separation and trajectory characteristics compared to the other weapons in the program, was released up to a maximum Mach number of 0.95 in both level flight and dives. The only reason for the speed limitation was that this boiler plate store was designed and constructed early in the program when high subsonic speeds were to be demonstrated by the Navy. It is felt that the separation behavior of this store at high subsonic speeds will continue to prevail supersonically as in the trend shown by the M-117M6. If this holds true, then serious consideration must be given to the 3.75 bluff star-fin shape as a future weapon configuration.

Weapon separation from the F-4/Conformal Carriage was characterized by the same uniform, predictable trajectories as experienced in the wind tunnel. That is, the separation behavior of all weapons from conformal carriage is vastly superior to that of weapons from conventional multiple racks. The reasons for this are fairly obvious when comparing the two flow fields and structures/platforms involved. The flow field for conformal carriage is quite regular, the only significant deviations from this being in the vicinity of the fore and aft ramps of the adapter when weapons overhang these areas. In these cases, pressure and flow differences lead to weapon pitch unless compensated for (e.g., by changing the orifice arrangement in the rack, by changing the ramp shape, or by spoiling the flow in these regions). In addition to the flow field, there is hardly any comparison between ejecting a weapon at an angle from the end of an oscillating beam and ejecting a weapon straight down from a solidly supported platform. That is, for the conformal carriage the ejection loads are transmitted fully and consistently to the store and the store is ejected in the correct direction.

These statements are borne out from the results of separating almost 200 weapons, all of them safely, from the F-4/Conformal Carriage over a large range of Mach numbers. It is particularly important to note that this includes almost 100 Mk-82's, notorious for their poor separation behavior when ejected at subsonic speeds using conventional methods. And these Mk-82's were safely separated in level flight and dives at high subsonic and supersonic Mach numbers.

It is therefore safe to say that the F-4/Conformal Carriage fighter/attack aircraft has true supersonic mission performance and weapons delivery capability.

HANDLING QUALITIES

A significant portion of the performance flight test included a qualitative evaluation of handling qualities which will be treated separately here. This discussion is based on pilot commentary rather than on "hard" flight data, although quite frequently supported by wind tunnel results. For the purist this may be inadequate, however, for others this type of information is the most valuable of all. Four Navy pilots and one Air Force pilot participated in this program.

Both the F-4 flight manual and wind tunnel results show that fuselage mounted stores have no effect on the aircraft longitudinal stability. Conversely, stores mounted on the wing cause a significant decrease in longitudinal stability. In fact, it is possible, for certain aft center of gravity locations, to cause an extremely dangerous situation with some store loadings. However, the safe stability for conformal carriage with stores was adequately demonstrated when the test pilots entered into both short and long period oscillations with no appreciable effects on the clean F-4 by adding conformal carriage and weapons. In addition, neither were stall characteristics effected when both high and low "g" stalls were entered, the stall speed remaining the same.

It was felt that the stall buffet boundary was slightly increased. Some airframe buffet occurred at higher speeds caused by flow interaction in the area of the aft row of Mk-82's. Remembering that this flow region led to some additional minor trouble during weapon separation, it is important to consider redesign of the aft fairing area on any future operational conformal carriage adapter. A peculiar situation did occur when M-117M6's were carried in conjunction with the two camera pods for the weapon separation tests. A fairly strong buffet occurred at high speeds as a result of shock interaction between these pods and the larger diameter stores. This phenomenon needs further evaluation, particularly if it is desired to carry some of the larger, less streamlined guided missiles on the wing pylons in conjunction with stores of about 18 inches in diameter or greater on conformal carriage.

Roll response differences were quite significant with the stores concentrated near the roll axis for conformal carriage. In fact roll response with conformal carriage and weapons is also quite similar to the clean F-4 (the F-4 fighter). This extrapolates into a combat situation quite favorably, particularly when considering the degradation in roll response when approcahing a target with a full load of weapons on wing mounted multiple racks.

Yaw stability seemed to increase with a loaded F-4/Conformal Carriage aircraft. This is somewhat logical if one considers the adapter and weapons as simply a lower extension of the fuselage. This has an advantage in combat, as indicated by the pilots on simulated dive bomb tracking runs. That is, target alignment is more easily maintained. This is quite important since any misalignments are quite difficult to correct without some means of direct side force control (such as can be produced by reaction jets or differentially deflected horizontal canards).

Also of interest were the results of doing low speed high angle of attack rudder reversals with F-4/Conformal Carriage. Roll due to side slip was increased with an accompanying decrease in adverse yaw due to roll when compared to the clean F-4. Again, extrapolating to a combat situation, it is quite significant that the F-4 is not hampered but slightly improved by the presence of the conformal carriage adapter when performing an evasive manuever. That is the configuration representative of departure from the target area after the weapons load has been delivered.

Based on the foregoing qualitative analysis it can be at least anticipated that a conformal carriage system installed on an F-4 aircraft can in fact enhance that aircraft's handling qualities to the extent of greatly improving the combat capability in the attack role. Range and speed performance have certainly been improved for an attack configuration both to and from the target. But also important is the agility of the aircraft particularly in situations requiring evasive manuever and offensive action.

FUTURE CONSIDERATIONS

This Conformal Carriage Flight Demonstration Program was just that - a demonstration of the effectiveness and potential of a new technology. Although it was not intended to evaluate operational situations within the scope of this program, much thought to the future has been given by all those involved.

Additional weapon loads particularly with weapon mixes need to be evaluated. Carriage of guided weapons is possible but more work remains. Air-to-air weapons must be included although they, in general, represent less of a problem. Some attention needs to be given to the aforementioned buffet occurance for certain store load situations at high speeds.

An ejector rack is needed for conformal carriage which some of the undesirable features of the LODE 14A rack (when applied to conformal carriage). Considerations of access during weapon loading, arming wire hookup, ejector cartridge installation and removal, and mechanical release and emergency jettison of installed weapons are most important. Additional considerations for more efficient ground handling and loading are required. It is proposed herein that the best arrangement is a permanently attached adapter structure/fairing with modular pallet inserts (one for each weapons row) which contain ejector racks and their associated structure. This allows for considerable flexibility and convenience. For instance, relatively small pallets would be involved which can be preloaded. Some or all of these could be replaced by detachable fuel tanks, gun packages, electronics suits, etc. as the mission required with a minimal penalty (if any) being paid (remembering that no one is about to fly the clean F-4 baseline aircraft into combat).

Above all, the necessary effort now required is to assimilate the data and experience from this program to establish the best possible approach and design for an operational adapter, i.e., a fleet retrofit to the F-4 aircraft, be it Air Force or Navy. Much more has been proven and learned. It has been shown that the F-4 aircraft need not be hampered when used in the air-to-ground role - in fact, it can be a fighter/attack aircraft in the true sense of the word (our first?).

CONCLUSIONS

The concept of conformal carriage has been successfully demonstrated. The approach taken by integrating analytical, wind tunnel, and full-scale flight efforts was an effective one. Although this program certainly had its share of problems, the overall program and its success was outstanding with a good balance of effort. However, it is most important to consider the future application of conformal carriage technology and the potential it holds.

- Conformal carriage must be seriously considered for any future attack or fighter/attack weapon system.

- Conformal carriage applied to the F-4 aircraft results in an exceptionally effective "here and now" weapon system for the combined air-to-ground/air-to-air role.

- Performance benefits are greatest in the most difficult flight regimes, i.e., at low altitudes and high transonic Mach numbers.

- The bluff weapon has emerged as an unusually effective free-fall weapon, both in its carriage efficiency, and in its superior separation and trajectory characteristics.

- This was a demonstration - the operational design will be even better.

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EPILOGUE

The true hero of this story is F-4B 148371, the 8th F-4B off the line and, while it was flying, the oldest active F-4 in the Navy. It was flown to NATC Patuxent in May 1973, with a cracked wing spar, to be stricken. In spite of its condition, old 148371 became the most sought after F-4 in the Navy. But Captain Jim Foster (OP506) kept his word, and F-4B 148371 now resides at NSRDC in its fully operable conformal carriage attire where it serves both as a tangible memorial to an outstanding advance in technology, as a static-test bed for check loading the weapon systems of the future - and as a testimonial to interservice cooperation, because the U. S. Army's 355th Heavy Helo Company at Ft. Eustis completed the tri-service loop and made the plan a reality.

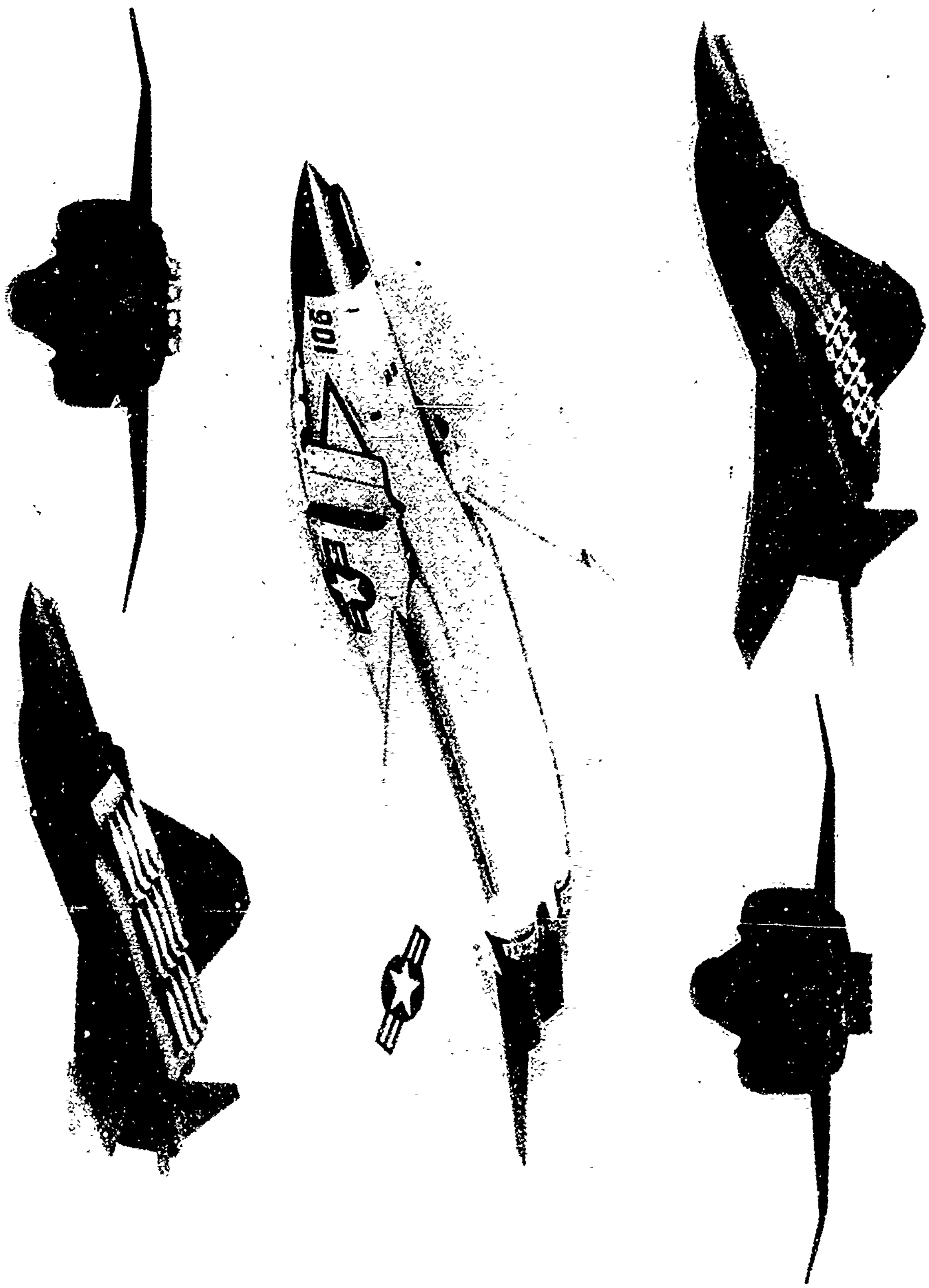

Figure 1 - The Conformal Carriage Concept

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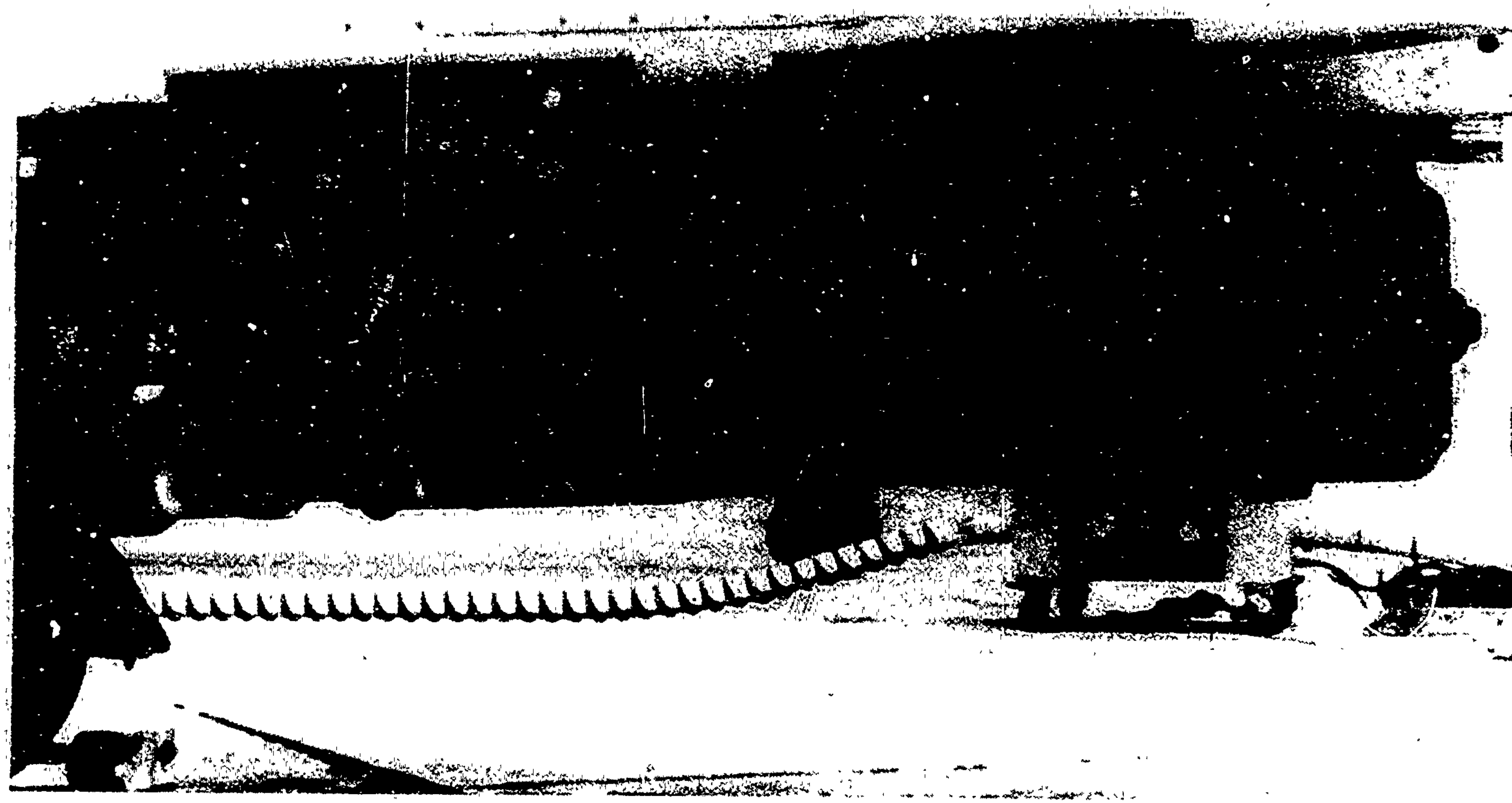
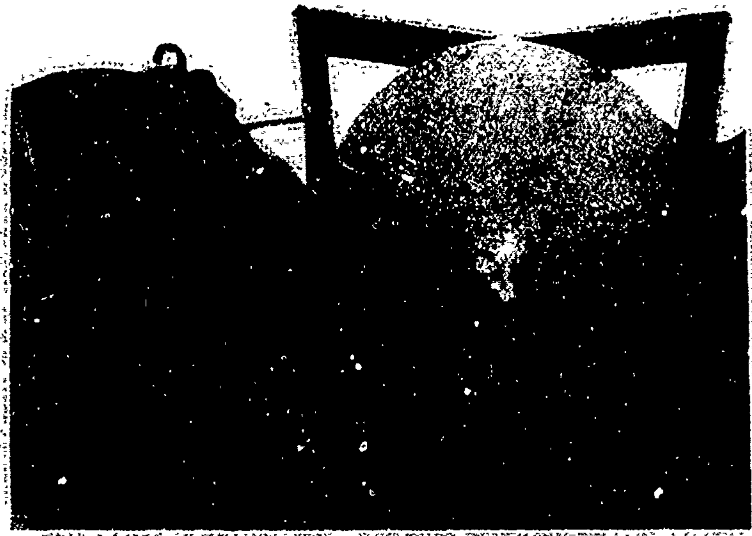
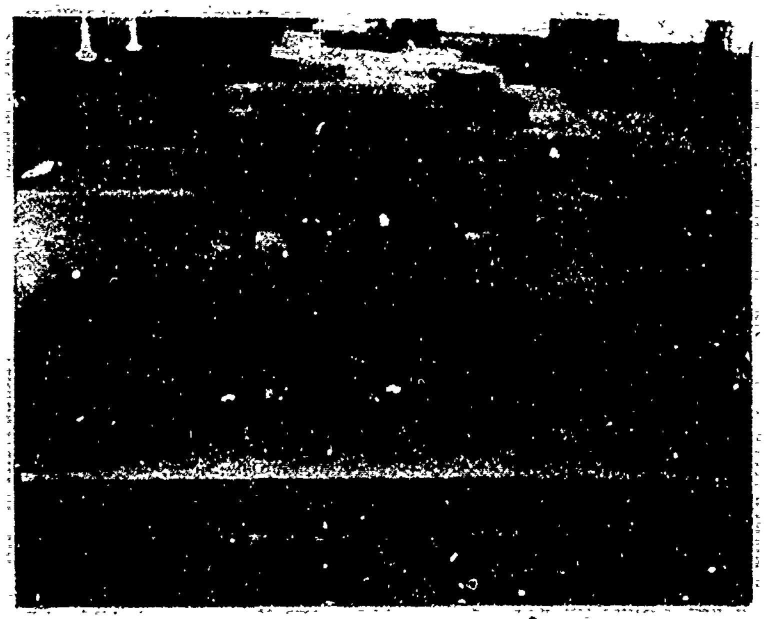


Figure 2 - The Air Force M-117M6 Bluff Bomb



End View



Side View

Figure 3 - The NSRDC 3.75 Bluff Bomb

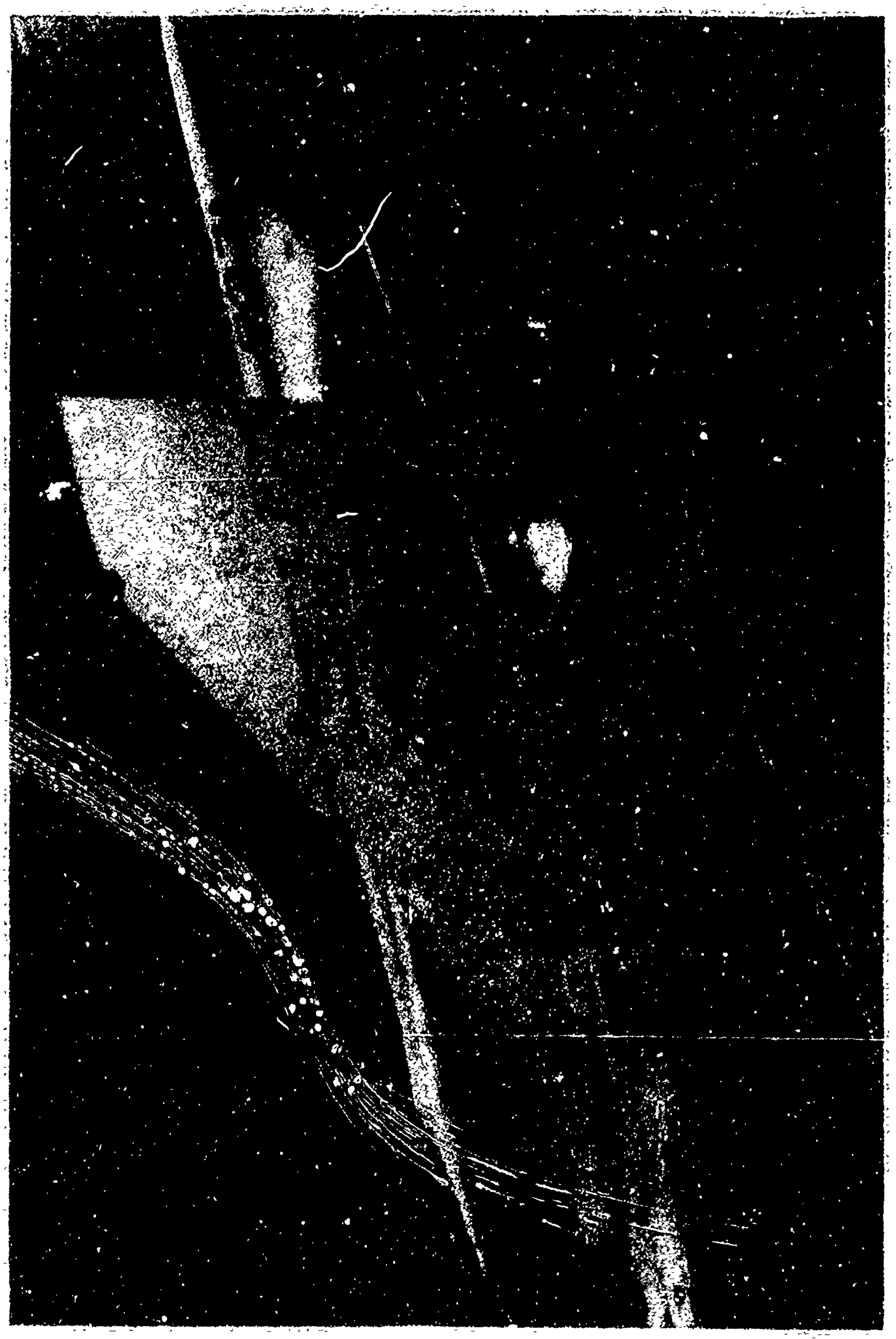


Figure 4 - The Conformal Carriage Adapter Installed

Figure 5 - The Conformal Carriage Adapter Assembly Process

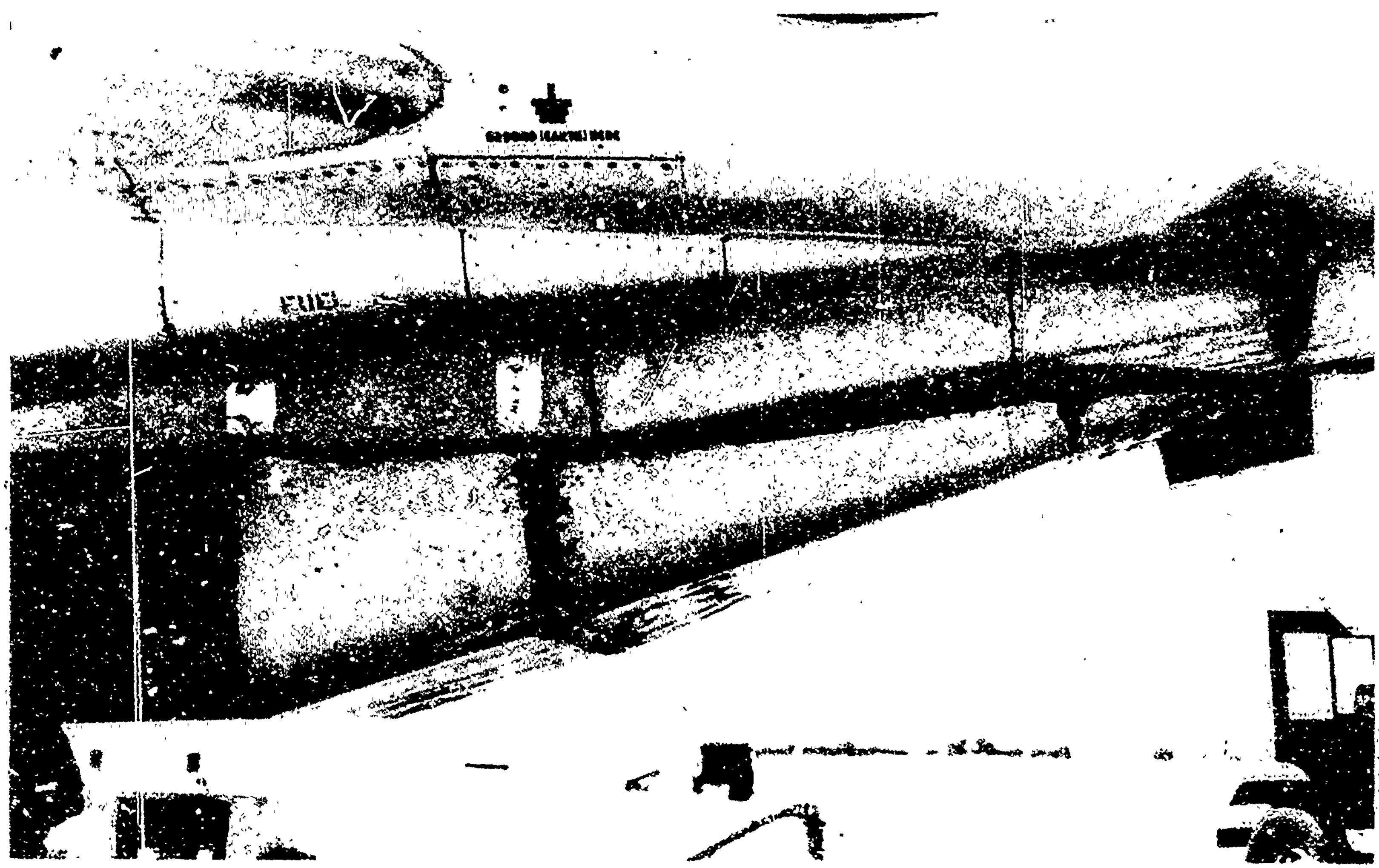


Figure 6 - Detacheble Forward Fiaring for NSRDC 3.75 Bluff Bomb

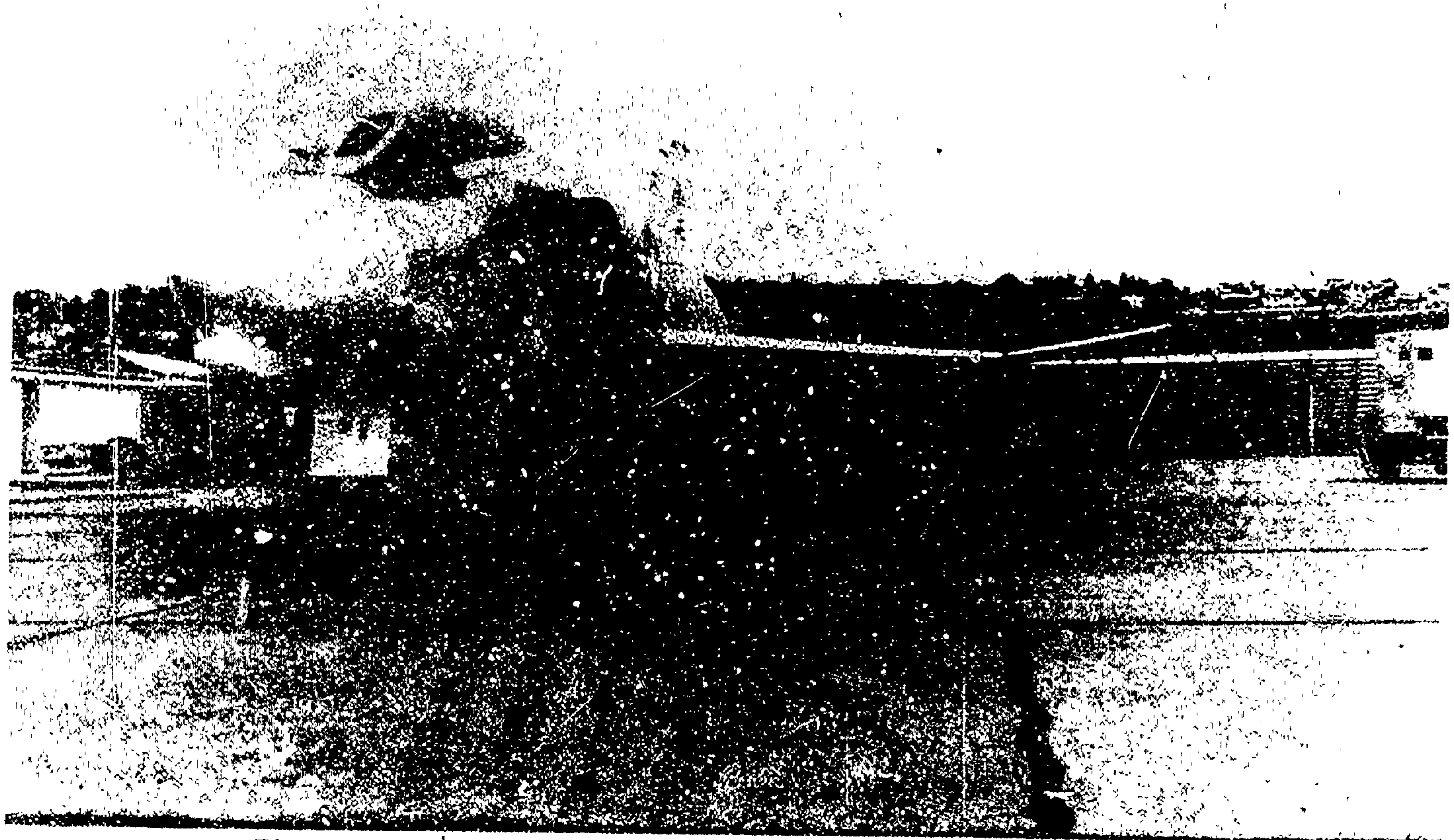


Figure 7 - F-4B Conformal Carriage with 12 Mk-82's Attached

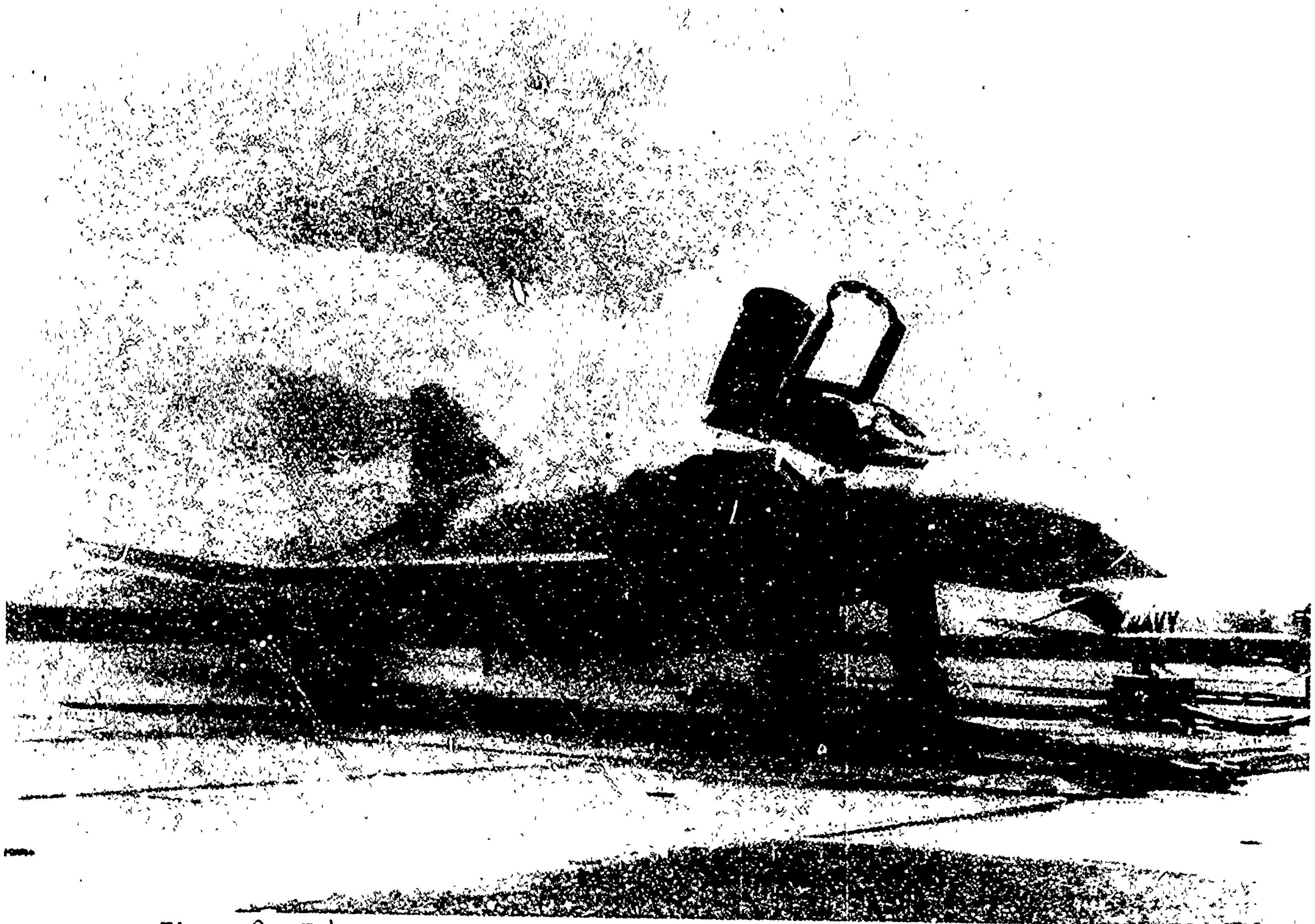


Figure 8 - F-4B Conformal Carriage with 9 NSRDC 3.75 Bluffs Attached

(a) Mk-82 GP Bomb Load

(b) NSRDC 3.75 Bluff Weapons Load

Figure 9 - F-4/Conformal Carriage Configured for Weapon Separation Test

AUTOBIOGRAPHY

Mr. Nichols received his B.S. degree in Aeronautical Engineering from the University of Maryland in 1960. He has since been with the Aviation and Surface Effects Department of the Naval Ship Research and Development Center and has specialized in aircraft/store separation and compatibility and transonic aerodynamics. He is head of the Aircraft Division and is currently involved in Conformal Carriage, Close-Coupled Canard, and Aircraft Conceptual Design programs. Mr. Nichols is a member of the American Institute of Aeronautics and Astronautics and the American Ordnance Association.

WEAPON CONFIGURED VEHICLE DESIGN
FOR ADVANCED TACTICAL AIRCRAFT
(U)
(Article UNCLASSIFIED)

by

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Boeing Aerospace Company
Seattle, Washington

ABSTRACT. (U) Future survival in tactical fighter combat will require efficient weapon carriage and delivery at supersonic speeds. Conversely, effectiveness in various operating environments requires advanced tactical aircraft to possess mission flexibility comparable to current fighters, but with improved handling qualities when carrying heavy overloads. Two weapon carriage concepts exist that may be incorporated into new fighter designs to resolve these conflicting goals. Advanced concepts of MER/TER type carriage possess adequate flexibility and, if properly integrated into aircraft design at the start, might provide good supersonic capability. The other concept with potential is conformal carriage, applying to tangent, tandem arrangement of external stores on the body of an aircraft in a low drag configuration.

This paper presents weapon configured vehicle design features resulting from a study undertaken to investigate the relative merits of Integrated Conformal Carriage and Advanced MER/TER Weapon Carriage when integrated into advanced tactical aircraft. The study was accomplished by configuring two airplanes for an identical design mission, each with different weapon suspension systems (conformal carriage and MER/TER carriage). Comparisons are made to assess the effect of the weapon suspension method on airframe design parameters and airplane performance.

LIST OF FIGURES

INTRODUCTION

Future survival in tactical fighter combat will benefit from efficient weapon carriage and delivery at supersonic speeds. Conversely, effectiveness in various operating environments requires advanced tactical aircraft to possess mission flexibility comparable to current fighters, but with improved handling qualities when carrying heavy overloads. Two weapon carriage concepts exist that may be incorporated into new fighter designs to resolve these conflicting goals. Advanced concepts of MER/TER type carriage possess adequate flexibility and, if properly integrated into aircraft design at the start, might provide good supersonic capability. The other concept with potential is conformal carriage, applying to tangent, tandem arrangement of external stores on the body of an aircraft in a low drag configuration.

This paper presents weapon configured vehicle design features resulting from a USAF-sponsored study undertaken to investigate the relative merits of Integrated Conformal Carriage and Advanced MER/TER Weapon Carriage when designed into advanced tactical aircraft. The USAF manager was Mr. R.K. Mills, Chief, Concepts Division, Directorate of Development Plans, Armament Development Test Center, Eglin AFB. The study was accomplished by configuring two airplanes for an identical design mission, each with different weapon suspension systems (conformal carriage and MER/TER carriage). Comparisons were made to assess the effect of the weapon suspension method on airframe design parameters.

BODY

ADVANCED MER/TER DESIGN APPROACH. An advanced aircraft configured at design outset for MER/TER carriage of heavy weapon loads as well as design mission loads, is shown in Figure 1. Specific design features have been incorporated to achieve maximum airplane performance while providing weapon installation flexibility and good weapon separation.

The unique feature of the aircraft is the canard or tail forward arrangement. The heavy weapon load requirements drove the configuration design in two ways:

- Pylon mounted stores must be located near the aircraft center of gravity for a stable release platform and minimum influence on directional stability, and
- Pylon mounted stores must be outside the wing flow field.

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Thus, the pylons extend well forward and below the wing with the weapon package center of gravity very near the aircraft center of gravity.

A straight wing was selected to minimize the cross flow between the pylon mounted weapons. The low wing configuration was selected to minimize interference drag between the weapons and the fuselage.

The engine location was driven by the nozzle spacing for minimum interference drag. The resulting engine installation influences the shape of the aft body.

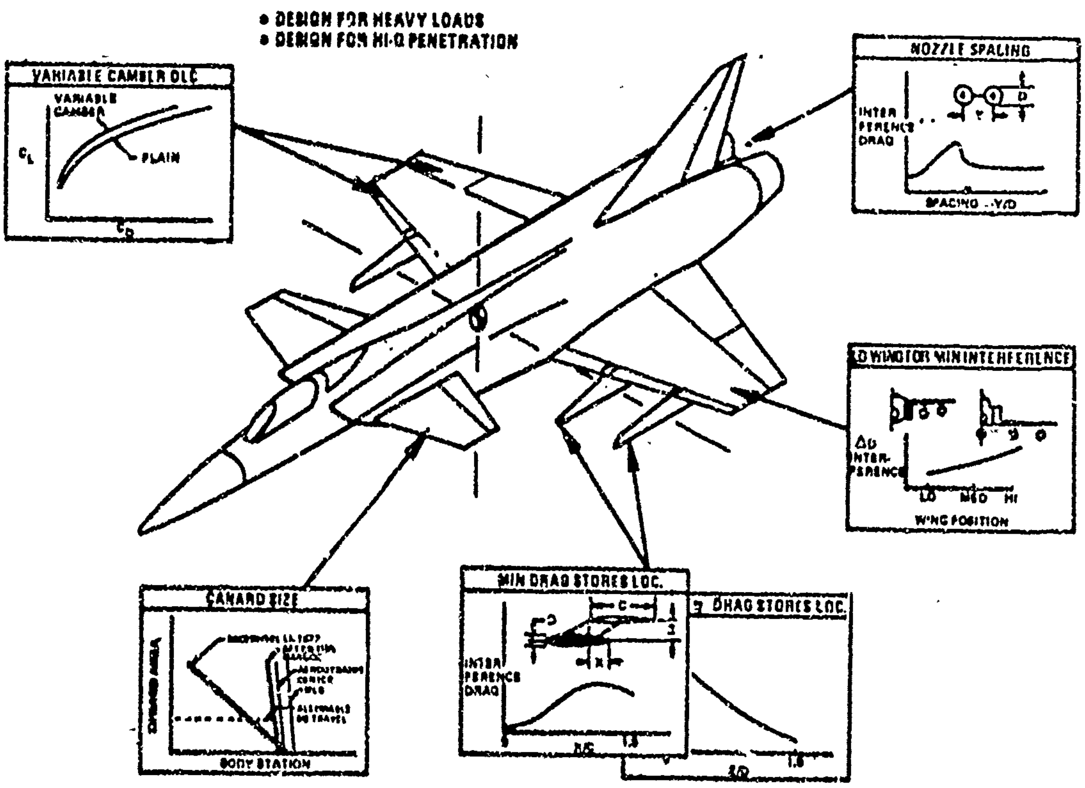

Figure 1: Advanced MER/TER Design Features

Wing loading and thrust loading were selected on the basis of transonic performance providng a survival capability and defensive air to air capability with a full load of weapons. The aircraft is shown in combat configuration in Figure 2. The payload is the BLU-58 bluff munition.

Figure 2: Combat Configuration-Advanced MER/TER Aircraft

INTEGRATED CONFORMAL CARRIAGE DESIGN APPROACH. An advanced aircraft configured at design outset for body mounted tangent, tandem store carriage (conformal carriage) is shown in Figure 3.

Integration of the weapon suspension into the body structure provides complete loading flexibility in a low drag configuration, good weapon release flow field, a minimum of add-on suspension equipment and freedom of vehicle configuration that produces a superior supersonic performance capability.

The unique feature of the aircraft is tailless variable sweep. Body mounting the weapons permits the variable sweep choice - proven for supersonic performance.

Weapon physical characteristics were found to have a strong influence on this aircraft configuration - particularly the large finned stand-off glide weapons. A requirement to carry four of these munitions was accommodated by a corner mount solution for low drag aircraft performance.

This weapon integration requirement drives the body, wing, landing gear and inlet geometry. Thus, weapon geometry and quantities specified at design outset will dictate design choices.

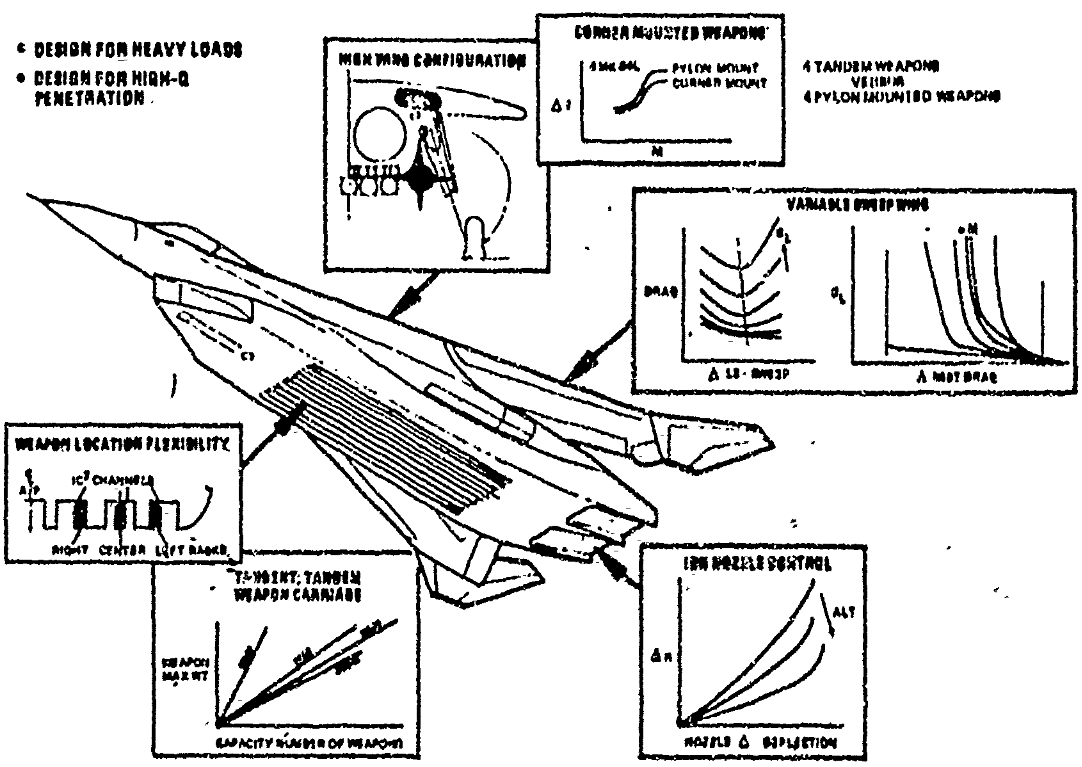

Figure 3: Integrated Conformal Carriage

The aircraft has been performance sized to compete with an F-15 type threat providing a survival capability and defensive air to air capability with a full load of weapons. The aircraft is shown in its combat configuration in Figure 4 - again with the BLU-58 bluff munition.

Figure 4: Combat Configuration-Conformal Carriage Aircraft

COMPARISON OF DESIGN RESULTS. The two weapon configured vehicles were intended to be different wherever differences would show a benefit to carriage of heavy loads and still provide good supersonic performance with the design load. Design differences in five subsystems are summarized as follows:

Weapon Suspension Structure - Figure 5. The weight increments compared include only the internal hard points and all pylons required. Pylon weights plus structural weight for wing and body hard points contribute 720 lbs. for heavy load air-to-ground capability on the MER/TER vehicle concept. The same capability when integrated into the body structure of the conformal carriage concept contributes 600 lbs. for rails and provisions - this is additional to a "minimum" body structure weight.

The MER/TER pylons (approx. 620 lbs.) can be removed for the design mission. The weight for carriage integration in the conformal carriage concept cannot be removed.

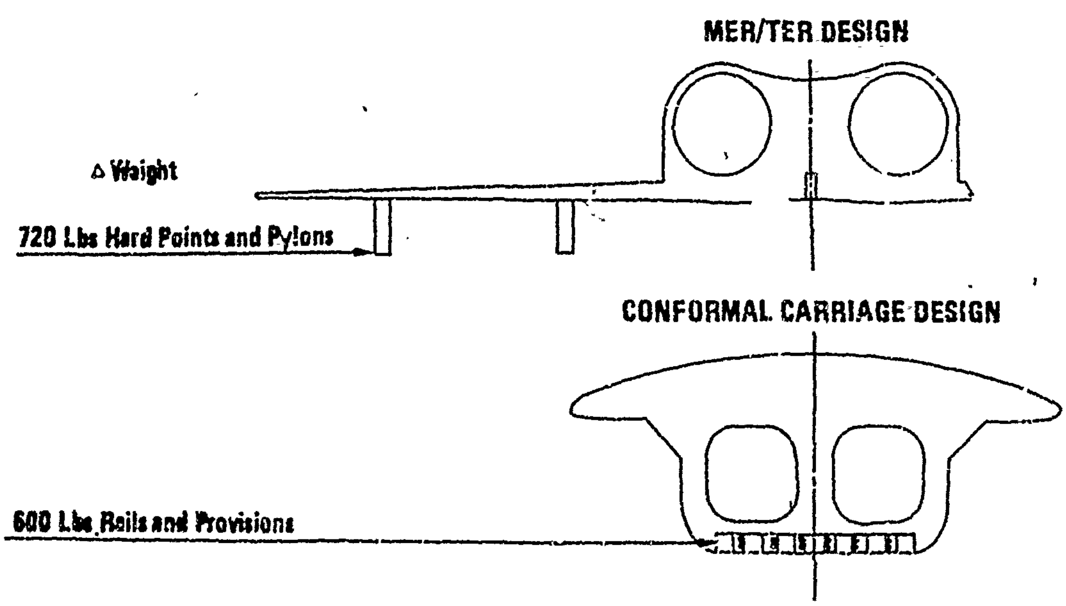

Figure 5: Effect of Weapon Carriage on Vehicle Design:Support Structures

Landing Gear - Figure 6. The MER/TER solution follows the classical approach of simple straight forward design to fit into the side body ahead of the wing front spar and well clear of pylon mounted stores. MER ejection clearance envelopes between centerline and inboard wing stations provide ample clearance for the forward retracting gear. This design represents a minimum weight main gear.

Main landing gear design for conformal carriage was developed around different requirements that add complexity and weight. The MK-84L, guided munition without folding fins, represents a worst case and a design challenge best met by fuselage corner mounting. Capability for four large finned weapons, twin tandem - corner mounted, was incorporated in the conformal carriage concept as a requirement for mission loading flexibility. This decision resulted in two major design features, the high wing location for weapon fin clearance and the long wide spread landing gear. A tandem gear design was considered and rejected as being too restrictive for other weapon loadings on the underbody. The 310 lb. additional weight was accepted as the best trade for full body load capability.

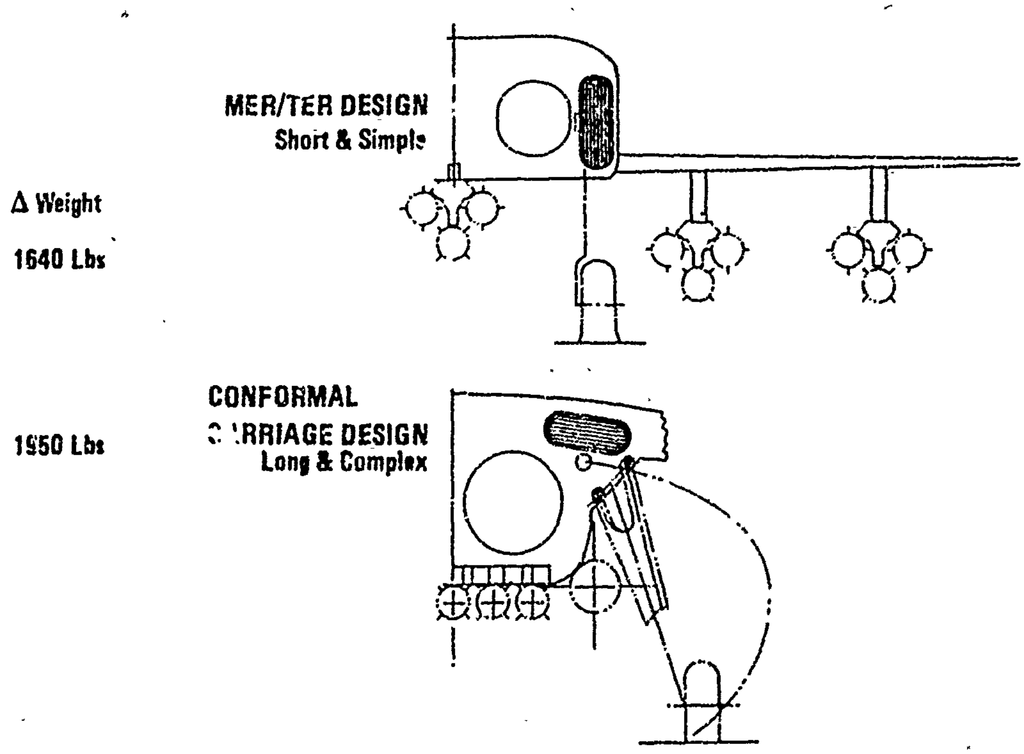

Figure 6: Effect of Weapon Carriage on Vehicle Design: Landing Gear

Wing and Controls Design - Figure 7. Wing geometry was an early selection for both concepts. The straight wing for MER/TER was selected to tailor the total vehicle for best weapon flow field and longitudinal stability with MER and TER pylon carriage. The resulting canard arrangement provides ample control with positive longitudinal stability. The weight contribution shown does not include an uncertain penalty for wing flutter on the MER/TER airplane.

The conformal carriage concept could have incorporated a fixed sweep wing and tail. However, variable sweep was selected because of superior aerodynamic performance - both subsonic and supersonic - because the body weapons carriage allows such design freedom while eliminating any concern for development of pivoting wing pylons.

Active controls show up to full advantage in the variable sweep tailless arrangement evolved for Integrated Conformal Carriage. The basic control concept employs rapid variable sweep to minimize the static margin around neutral plus thrust vectoring by two dimensional nozzles to augment pitch control derived from wing tip elevons. This combination is approximately 1380 lbs. heavier than the MER/TER combination and therefore must show superior performance to produce a competitive solution.

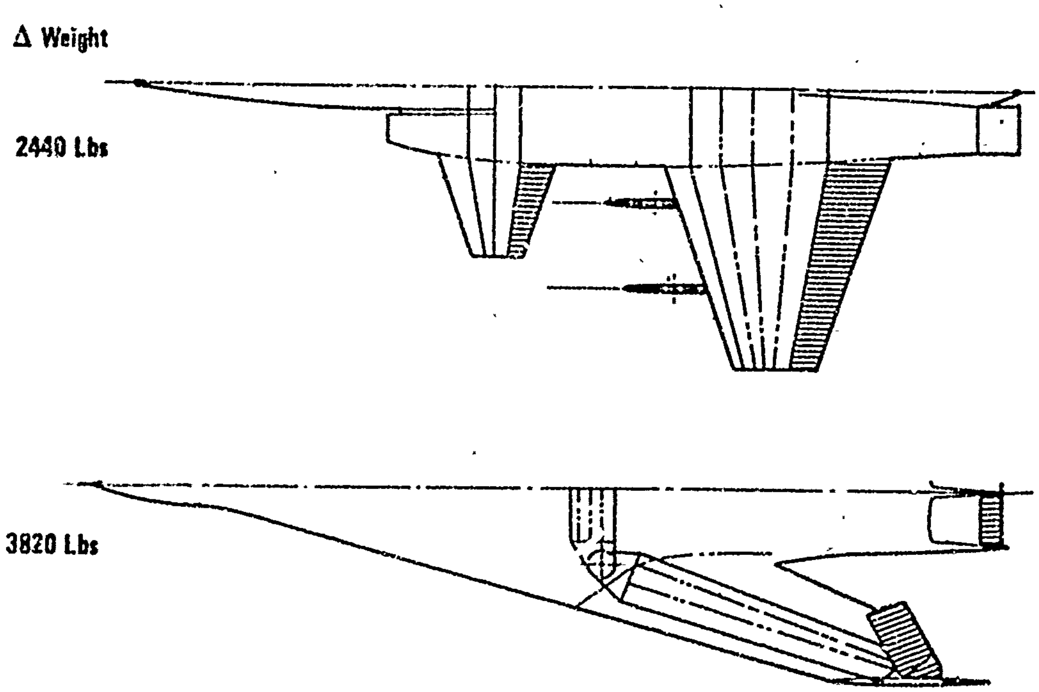

Figure 7: Effect of Weapon Carriage on Vehicle Design: Wing & Controls Design

Inlet Geometry - Figure 8. Two variations of the same basic inlet were evolved. The MER/TER weapon carriage concept allowed a shorter inlet system. A longer inlet diffuser was incorporated into the conformal carriage concept to provide a good nose wheel installation and to place inlet shock flow ahead of all weapons. By this arrangement all weapons lay inside the supersonic shock flow produced by the aircraft nose. The weight penalty of approximately 130 lbs. was accepted as the best compromise for design integration.

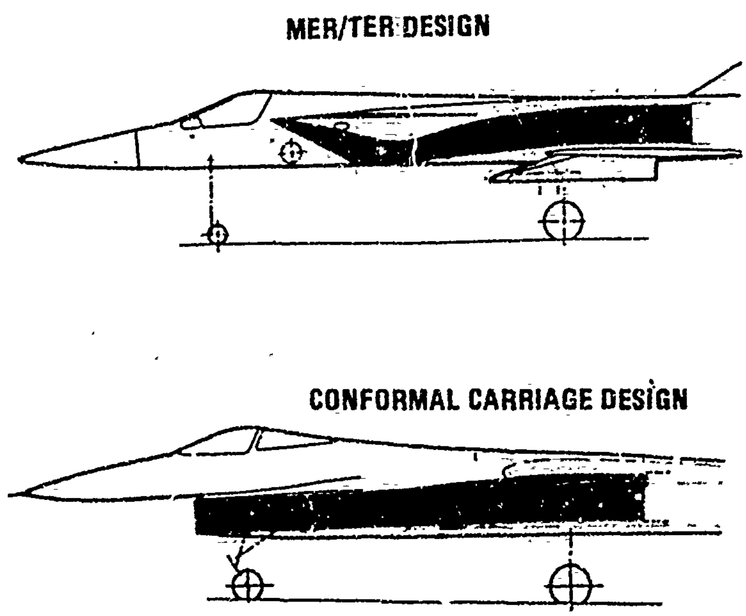

Figure 8: Effect of Weapon Carriage on Vehicle Design: Inlet Geometry

System Access - Figure 9. Any new vehicle design must include system access as part of weapon/airframe integration. In the case of Integrated Conformal Carriage, new considerations are added. While classical MER/TER arrangements utilize the fuselage lower body for system and engine access, conformal carriage requires the underbody to be dedicated to weapon suspension. Studies of this problem have shown that side body access can be very good if considered early. The conformal carriage installation employs side access for engine accessory replacement as well as engine change. This solution allows weapon carriage structure to occupy the lower body space normally used for engine accessories. The tailless arrangement contributes to the minimum weight penalty of this approach because tail loads are symmetrical - due only to thrust vectoring.

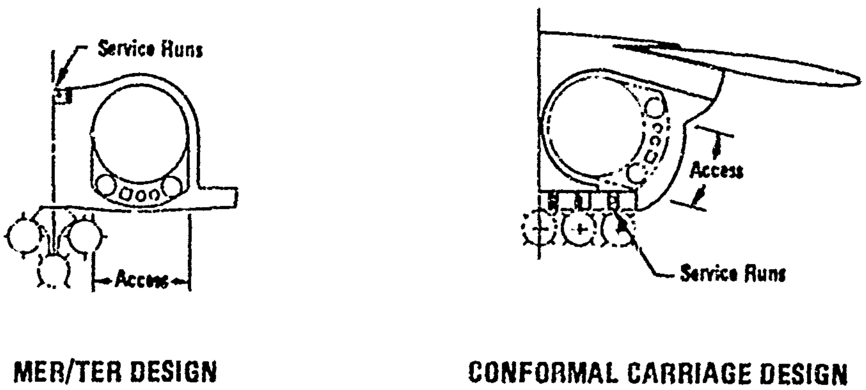

Figure 9: Effect of Weapon Carriage on Vehicle Design: System Access

DESIGN FEATURE CONCLUSIONS.

- Conformal Carriage airplane weighs 8% more than the MER/TER airplane.
- Large finned weapons have greater integration impact on Conformal Carriage airplane.
- Both airplanes have mixed store loading flexibility - this was a design goal.
- Body mounted stores permit more freedom of wing and control system options.

MISSION PERFORMANCE COMPARISONS. The final evaluation of the two optional weapon suspension systems lies in the effect on the airplane's performance.

The design choices discussed previously resulted in a Conformal Carriage configuration which was 8% heavier. The performance comparisons were made at equal gross weights for the two airplanes; therefore, the Conformal Carriage airplane carried 8% less fuel on all missions.

The design mission used is a mid-altitude, high Mach number penetration mission.

Comparison of the MER/TER and Conformal Carriage airplanes on this mission, Figure 10, show that the Conformal Carriage vehicle has a 23% greater mission radius than the MER/TER vehicle with 8% less fuel. This difference increased to 30% using 600 gallons of external fuel on each aircraft.

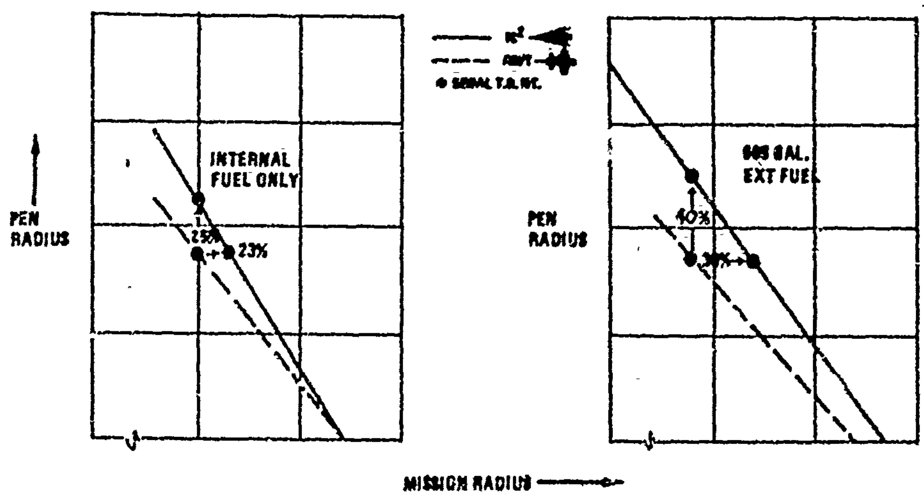

Figure 10: Design Mission Performance Comparison

When looking at two heavy weapon loads which are of particular interest (designed as loads 1-2 and 1-5) a clear advantage of the conformal method of weapon carriage occurs in terms of range and penetration speed.

Mission 1-2 weapon loads for both airplanes are equal numbers of AGM-65 (Maverick) missiles. Figure 11 illustrates total mission radius as a function of penetration Mach number. The examples shown on this figure show penetration speed increases in a 10-13% range for the Conformal Carriage vehicle, depending on mission cruise altitude.

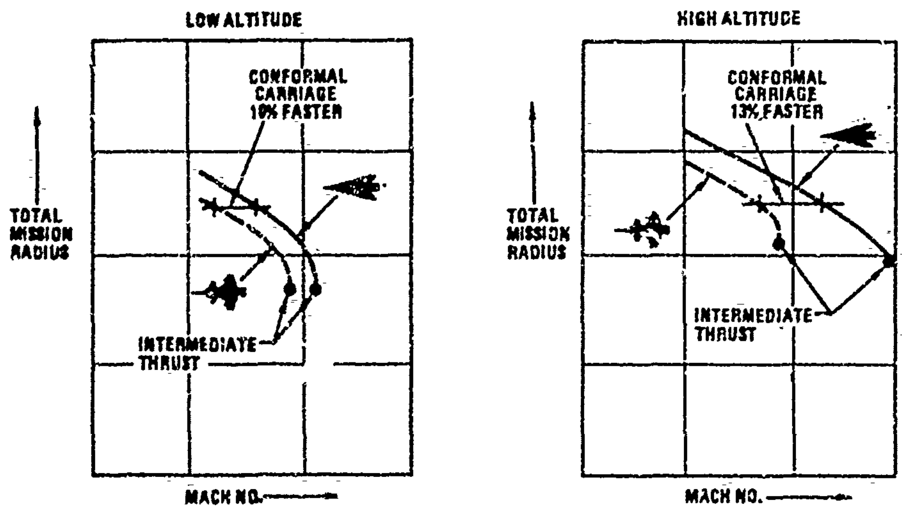

Figure 11: Mission 1-2 Radius Comparison

Mission 1-5 weapon loads for both airplanes are equal numbers of high-density BLU-58 bluff shaped munitions. These maximum mission loads were shown on previous Figures 2 and 4. Figure 12 also shows penetration speed increases in a 9-12% range for the Conformal Carriage vehicle, depending on mission cruise altitude.

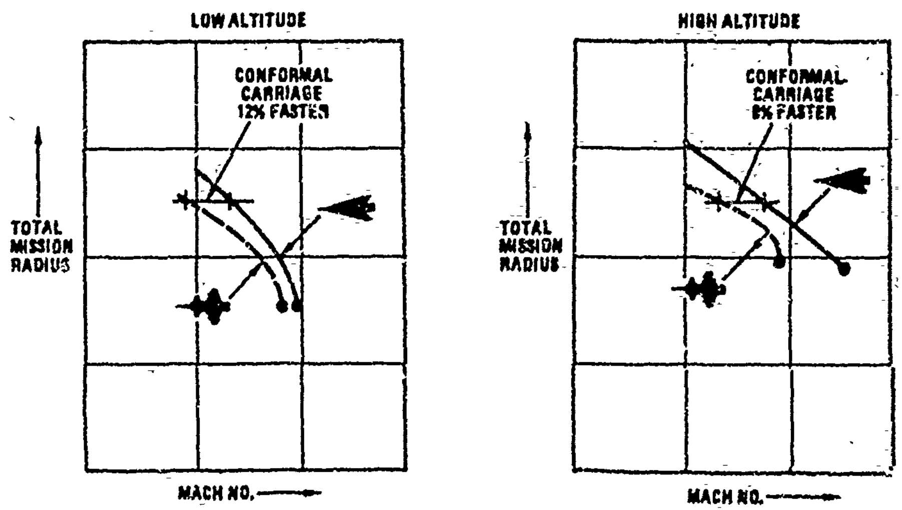

Figure 12: Mission 1-5 Radius Comparison

SUMMARY

The weapons considered for integration on the two advanced aircraft favored the MER/TER configuration since all the weapons themselves were designed to be carried on wing mounted MER and TER suspension systems. Despite that constraint, the Conformal Carriage configured airplane turned out to have superior performance in terms of penetration speed, combat agility, range and weapon loading flexibility.

The performance differences would be much larger if the weapons considered were tailored for tangent, tandem mounting. Weapon design will have a significant impact on airframe design choices as previously discussed.

If conformal carriage of weapons provides such significant aircraft performance improvements, why shouldn't it be adopted as the standard method of weapon suspension on all future aircraft?

Such a commitment faces many hurdles, some of which are hardware and some of which are organizational.

The practical hardware orientated hurdles include:

- The existing inventory of weapons.
- Commonality of MER's and TER's with other existing aircraft.
- Existing ground support equipment.

The organizational hurdle includes:

- Weapons and airframes being designed by separated organizations with limited communication - both in government and industry.

Past USAF studies with stated high "q" penetration and weapon delivery requirements have resulted in aircraft and internal weapon bays and gross weights approaching 100,000 pounds. Separation of weapons from the weapon bays at high "q" conditions is highly questionable.

Conversely, the emerging technology of conformal carriage has demonstrated clean, safe, separation in actual flight test at speeds in excess of Mach 1.5.

Incorporation of the conformal carriage technology into future tactical aircraft will be a necessity for survival in the sophisticated defense environment of the 1980's. It will not be an easy road. Difficult organizational decisions will be required and will have to be defended. The payoff will be an integrated airframe/weapon system capable of high "q" penetration and weapon delivery, no larger than current tactical aircraft such as the F-4.

AUTOBIOGRAPHY

Mr. Gilbert received B.S. degrees from the University of Colorado in Aero Engineering and Business Administration. He is presently Deputy Program Manager of the Integrated Propulsion Control System contract sponsored by the Propulsion Laboratory. Prior to his present assignment, he was the Armament Project Engineer for Advanced Tactical Combat Airplane Programs. His responsibilities included development of advanced armament systems for Boeing's lightweight fighter proposal; conformal carriage for the F-4; study manager for "MER/TER Versus Conformal Carriage for Advanced Tactical Aircraft" contract; and armament systems for Boeing's sea control fighter proposal.

Mr. Gilbert was the Armament Systems Manager for Boeing's B-1 proposal which included weapon/airframe integration and the stores management system.

Mr. Gilbert spent two years on the SRAM Program as the Lead Design Engineer responsible for development of the B-52 rotary launcher.

Mr. O'Neill received a B.S. in Aero Engineering from the University of Colorado. He is principal engineer for mission subsystems in the Tactical Combat Airplane Program of Boeing Aerospace Company. Mission subsystems include all weapon-airframe integration and man machine interface design. He served in this capacity on the MER/TER Versus Conformal Carriage contract for F-4 and Advanced Tactical Aircraft.

After joing The Boeing Company in 1959, Mr. O'Neill had both preliminary and detailed design assignments in the following areas: B-70 wing design, Minuteman missile program, Saturn/Apollo program, Navy advanced surface missile system program and Boeing strategic systems exploratory design. In early 1971, Mr. O'Neill joined the Aeronautical and Information Systems Division, Tactical Combat Airplane Program (TCAP) where he participated in configuration definition for the lightweight fighter proposal and other advanced tactical aircraft, including armament integration.

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LARGE CLUSTER WEAPON FEASIBILITY DEMONSTRATION FLIGHT TEST (U)

(Article UNCLASSIFIED)

by

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ABSTRACT. (U) The clustering of high density weapons offers a new method for weapons carriage/release on current attack aircraft. The Large Cluster concept provides a more efficient, lower captive drag external weapons carriage system which can also be used as an interim system for carrying high density modular weapons. Analytical and experimental studies were verified in a flight test program designed to demonstrate the feasibility of such a large cluster system.

The configuration selected for the flight test vehicles was based on aircraft compatibility and carrier compatibility studies, wind tunnel static and dynamic stability tests, and on wind tunnel dynamic store separation tests. The flight test program consisted of six drops from the centerline station of an A-4 aircraft. Trajectory, drag, aircraft/store separation, and ground impact pattern data were obtained.

The flight tests successfully demonstrated the feasibility of the use of a canisterized approach to clustering and carrying high density bluff munitions. Good agreement between wind tunnel and flight test data was obtained.

LIST OF FIGURES

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20. Lofted Trajectory

    (a) Three Second Door Delay

    (b) 30 Second Door Delay

21. Close Air Support Mission Radius Comparison

INTRODUCTION

The large cluster free-fall weapon concept was originally formulated to provide a method of external carriage of airborne muntions in an aerodynamically more efficient manner than existing methods using MER and TER racks. The Aviation and Surface Effects Department (ASED) at the Naval Ship Research and Development Center became interested in 1967 in improving the separation and captive drag characteristics of mulitple munitions carriage. Accordingly, an in-house program under Independent Research/Independent Exploratory Development funding was initiated the same year with the goal of exploring concepts for pylon mounting the equivalent of a load of Mk-82 weapons on a Multiple Ejector Rack but with lower captive drag and improved separation.

It soon became evident that some type of clustered approach would be necessary to obtain a good streamlined package. Numerous methods of submunition deployment and arrangements (i.e., shapes and packaging) were examined in detail. The result was two cluster concepts utilizing different deployment methods. One was for a dispenser which, after separation from the aircraft would eject the subweapons radially outward from the flight path. This method was referred to as lateral deployment. The other method was for a longitudinal deployment scheme, where the subweapons would be extracted from the rear end of the dispenser, one at a time, by a small drogue chute attached to each subweapon. Studies, including some small scale wind tunnel tests, were performed on numerous subweapon shapes.[1] Compatibility studies, both for aircraft and carrier interfaces, established a maximum practical size for the cluster. The length constraint was imposed by the bomb elevator dimensions aboard the carrier and the diameter constraint was imposed by compatability with the A-4 aircraft. Further studies[2] showed that optimum weights were in the 2000 and 3500 pound classes to maximize the possible weapons loads of current operational Navy combat aircraft. Performance studies, using estimated values of drag area for the cluster, showed that improvements in mission radius of fifteen to twenty percent were obtainable with the same aircraft carrying the large cluster as opposed to carrying an equivalent load of Mk-82's on MER's.

In Fiscal Year 1969, ASED received funding under NAVAIR sponsorship to continue and refine the concept. At this point, sufficient information was available to make a decision to eliminate the lateral

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1. Strachan, Brian C. Preliminary Stability Studies of Shapes Suitable for High Density, Clustered Packaging. Aerodynamic Lab. Tech Note AL-80. Naval Ship Research and Development Center, Nov 1968.

2. Nichols, James H. Big Stick Compatability Study. Part 1: Weights. Aerodynamics Lab. Tech Note AL-104. Naval Ship Research and Development Center, Apr 1969.

deployment scheme because a linear subweapon pattern was preferred to a circular one and because of the requirement for folding stabilizing devices for the subweapons which would add to the complexity and cost. Furthermore, the longitudinal method was being successfully used in the Fuel/Air Explosive (FAE) Weapon although for lower density and fewer subweapons. It was also decided that the longitudinal deployment method wouuld be demonstrated by a full scale flight test. The current concept became known as BIG STICK.

This paper will discuss some of the development work leading up to the flight tests and the results of the flight tests.

DESCRIPTION

The large cluster weapon is comprised of six subweapons arranged in a tandem cluster in a cylindrical dispenser as shown in Figure 1. The overall length is 164.1 inches, close to the maximum length of 165 inches required by carrier bomb elevators as stated previously. Allowing for a suitable nose fairing and room for forward and aft dispenser structure, a length of 150 inches remained for the subweapons. Since six subweapons were desired, the length of each subweapon had to be 25 inches. A 16 inch diameter was required to obtain sufficient volume in each subweapon for a 500 pound-class warhead based on the density of H.E. The subweapon weight for these flight tests was 485 pounds using concrete fill.

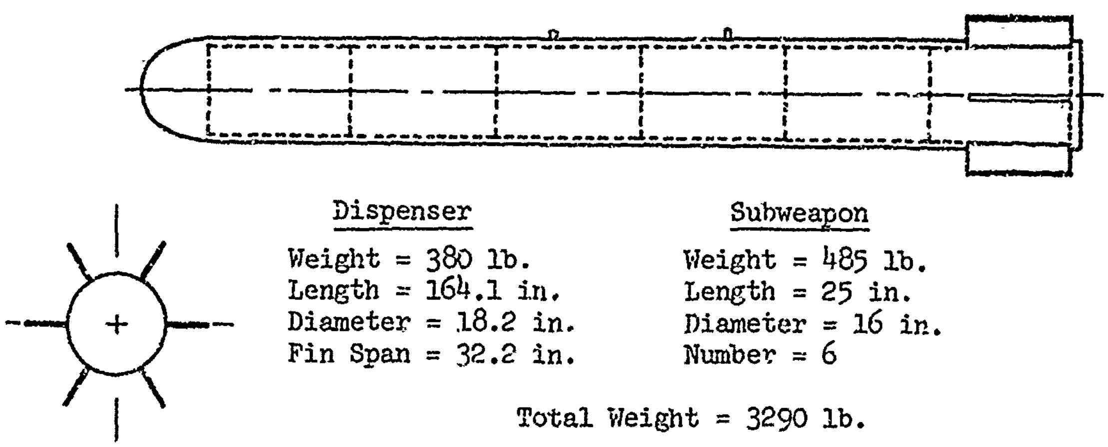


Figure 1 - Big Stick Cluster Weapon

The dispenser had to be slightly over 18 inches in diameter to provide room for adequate structure to carry the flight loads and to provide a system of rollers or conveyors to facilitate subweapon loading and extraction. As such, the dispenser weighed 380 pounds. The all up weight of the system with six 485 pound subweapons is 3290 pounds.

Deployment of the subweapons is by a small drogue chute attached to the aft end of each subweapon. The chutes were designed by Code 030 of the Naval Ordnance Laboratory for a terminal velocity of 350 feet per second with a 500 pound load. The resulting design was a two foot diameter cross parachute. With a 485 pound load, the terminal velocity is about 328 ft/sec as shown by flight test data in Figure 2.

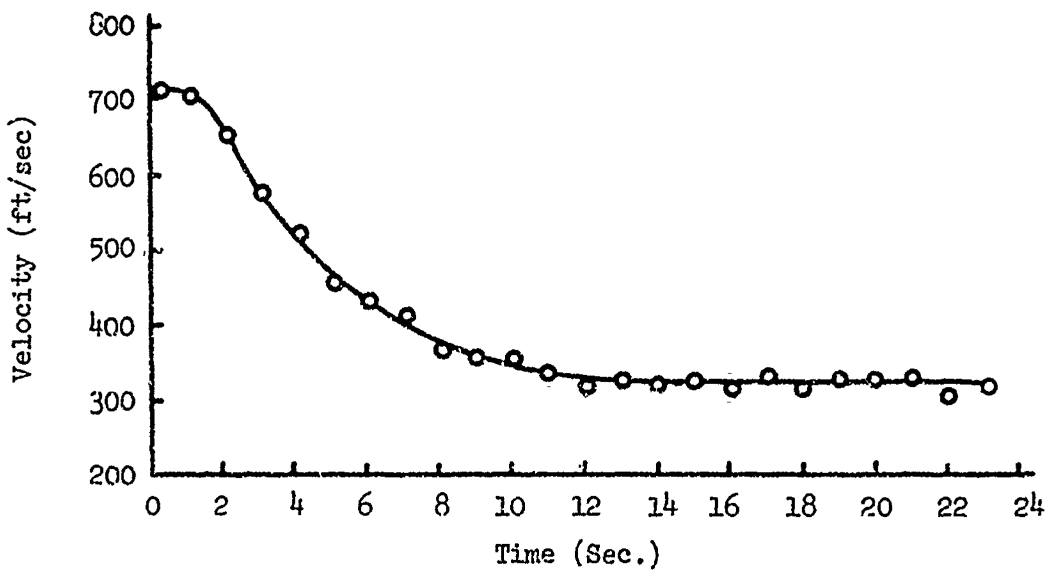


Figure 2 - Subweapon Velocity Profile

The dispenser structural design was based on loads calculated using MIL-A-8591. Since this was only a feasibility demonstration program, the structural design was not optimized. Planned drops were to be from straight and level flight so that a 2 g flight envelope was judged sufficient for the store. Loads were estimated for 3.5 g and the dispenser designed accordingly. The dispenser was then static tested to 3 g and the flight envelope restricted to 2 g to provide an adequate safety margin.

The dispensers were constructed by the Naval Aerospace Recovery Facility (NARF), El Centro, California. The structural arrangement is shown in Figure 3. The dispenser is constructed of a $\frac{1}{4}$ inch thick aluminum tube 17.7 inches in outside diameter by 50 inches long. Telescoped over this and butting at the center are two similar 18.2 inch outside diameter, $\frac{1}{4}$ inch thick aluminum tubes. Six roller rails, fabricated from extruded aluminum channel sections, are evenly spaced

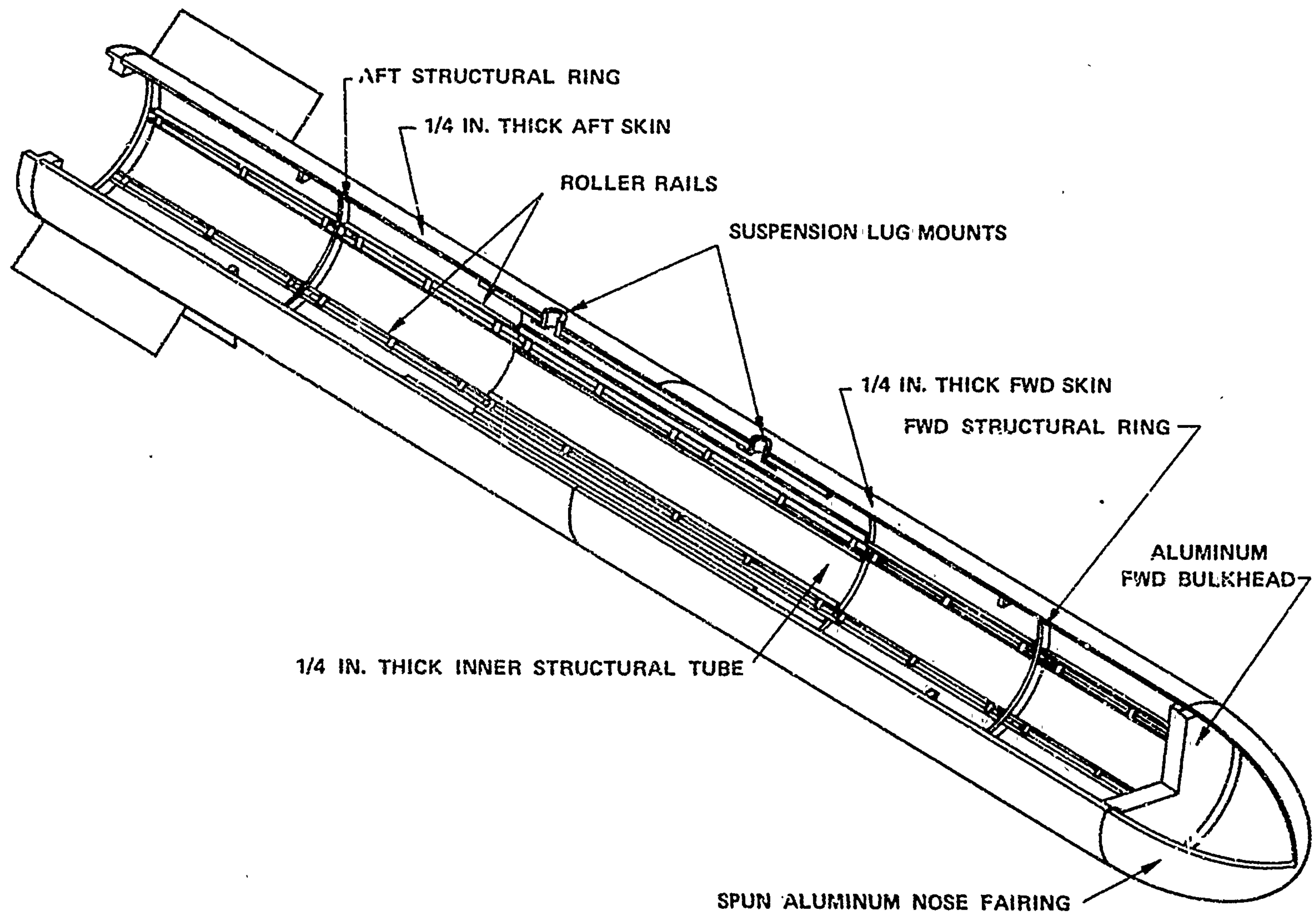


Figure 3 – Dispenser Structural Arrangement

around the inside of the cylinder and are used to stiffen the $\frac{1}{4}$ inch skin as well as to convey the subweapons. Tangential loads are carried by the skin and by two structural rings to which the skin is bolted. Other tangential loads are carried by the aluminum bulkhead at the forward end of the cylinder and by the specially shaped ring at the aft end.

This structure has proven quite satisfactory in its simplicity, light weight, and strength. No deflections in the bending mode could be measured in the 3 g static test. It is felt that much higher loads could have been withstood, however, further loading was avoided since all dispensers were needed for the flight tests.

The subweapons were fabricated from standard 16 inch diameter steel pipe of 3/8 inch wall thickness. One inch thick steel plates were welded in the aft end of each subweapon and a similar steel plate was bolted in the forward end. The aft plate is recessed about 1 3/8 inches to provide a space for the drogue chute pack. The subweapons were filled with concrete of proper density to bring the weight up to 485 pounds each. Subweapon details are shown in Figure 4.

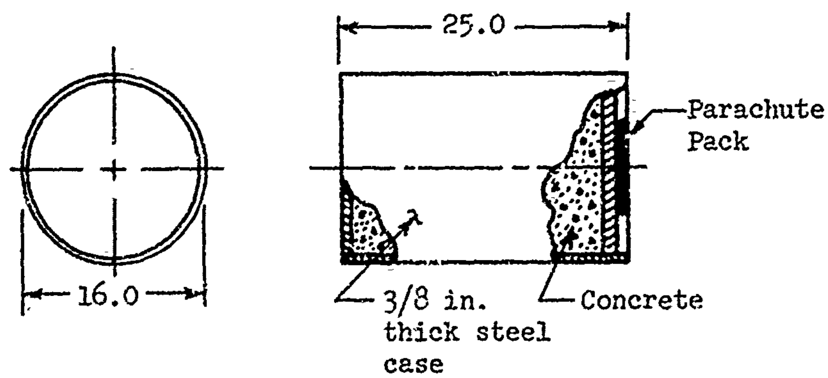


Figure 4 - Subweapon Details

Operationally, Big Stick works in the sequence shown in Figure 5.

1. The store is ejected from the aircraft.
2. After a pre-selected time period, the door at the aft end of the dispenser is blown away and pulls the deployment bag from the first drogue chute.
3. The drogue chute inflates and pulls the first subweapon from the dispenser. Attached to the front of the first subweapon is the deployment bag for the second drogue chute. This bag is removed as the first subweapon is pulled away from the dispenser.
4. The second drogue chute inflates and pulls out the second subweapon which, in turn, pulls the deployment bag from the third drogue chute.

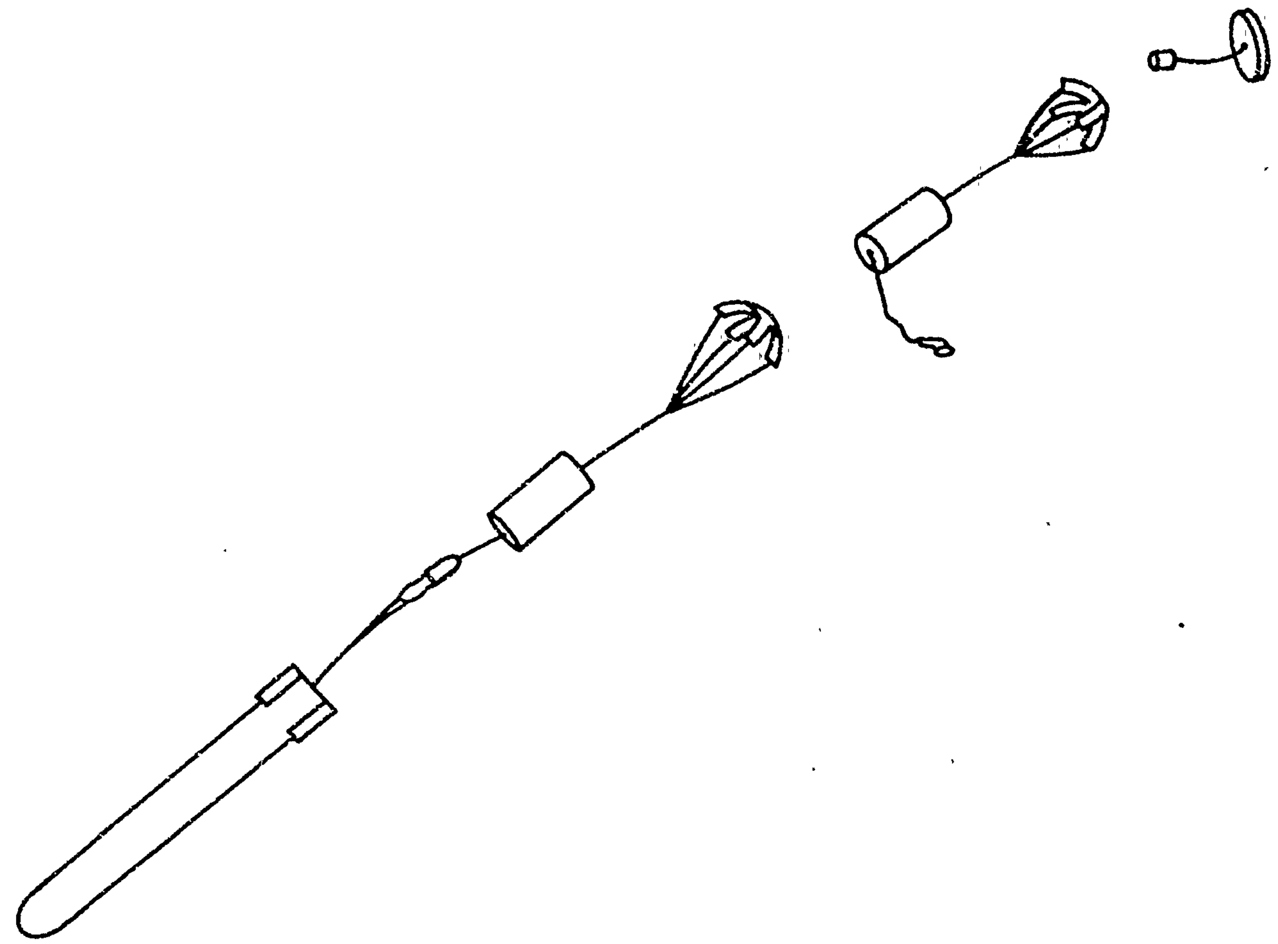


Figure 5 – Big Stick Subweapon Deployment

5. The sequence is repeated until six subweapons have been deployed.

Both the feasibility demonstration vehicle and the operational Big Stick operate in the above sequence. The primary difference is in the method of arming and deploying the door on the dispenser. The operational Big Stick would employ a fuse in the nose to detonate a flexible linear shaped charge located in a machined groove around the circumference of the door. The linear charge would shear the dispenser skin forward of the bolts holding the door and propel it aft from the dispenser. Each subweapon could also have the ability to split longitudinally and deploy the bomblets which comprise the subweapon warhead. The weapon could also be used as a single 3000 pound bomb.

In the interest of saving time and cost, the demonstration vehicle made use of a simple door deployment scheme developed by NARF. This device uses standard ejector cartridges to deploy the door and therefore did not require a special clearance for airborne ordnance.

STABILITY AND SEPARATION TESTS

FIN CONFIGURATION

It was desired to have a stable vehicle with good damping characteristics to insure good aircraft/store separation and to provide a stable platform from which to extract the subweapons. Several different fin configurations were examined in a dynamic stability test conducted in the NSRDC 7 x 10 foot transonic wind tunnel. A 0.242 scale model of the Big Stick vehicle was used. Tests were conducted with each fin planform shape using four and six fins equally spaced about the aft end of the dispenser. The fixed geometry configurations are shown in Figure 6. Results from the tests on these configurations are shown in Figure 7.

The static stability derivative $\frac{\partial C_m}{\partial \alpha}$ and the dynamic stability derivative $\frac{\partial C_m}{\partial \alpha} + \frac{\partial C_m}{\partial \frac{\dot{\alpha} \ell}{2V}}$ where

C_m = pitching moment coefficient

α = angle of attack

$\dot{\alpha} = \frac{\partial \alpha}{\partial \text{ time}}$

ℓ = reference length (ft)

v = free-stream velocity (ft/sec)

are shown plotted against angle of attack with Mach number as a parameter. The data show that only configurations 1 and 2 with six fins are both statically and dynamically stable over a large range of α. Configuration 1 was selected since it provided the desired stability characteristics and did not add to the overall length of the dispenser as did configuration 2.

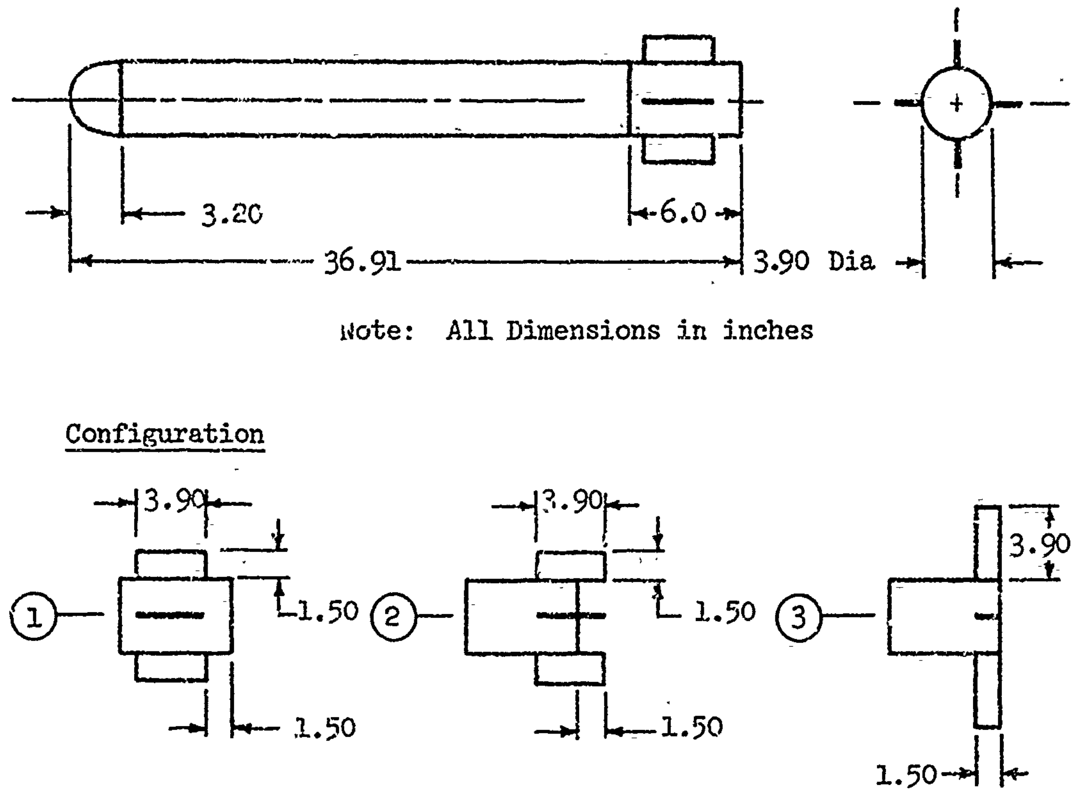


Figure 6 - Big Stick 0.242 Scale Dynamic Test Wind Tunnel Model with Three Fin Configurations

Some folding fin arrangements were tested which gave satisfactory stability characteristics with only four fins but these were rejected because of the additional mechanical complexity involved in unfolding the fins after separation of the store from the aircraft.

The flight tests have shown this fin arrangement to provide a very stable dispenser. Virtually no oscillation can be detected from the film coverage of the flight tests.

DYNAMIC SEPARATION TESTS

To insure safe store separation, dynamic separation tests of a ten percent scale Big Stick model from a ten percent scale A-4E aircraft model were performed in the NSRDC 8 x 10 foot subsonic wind tunnel. The

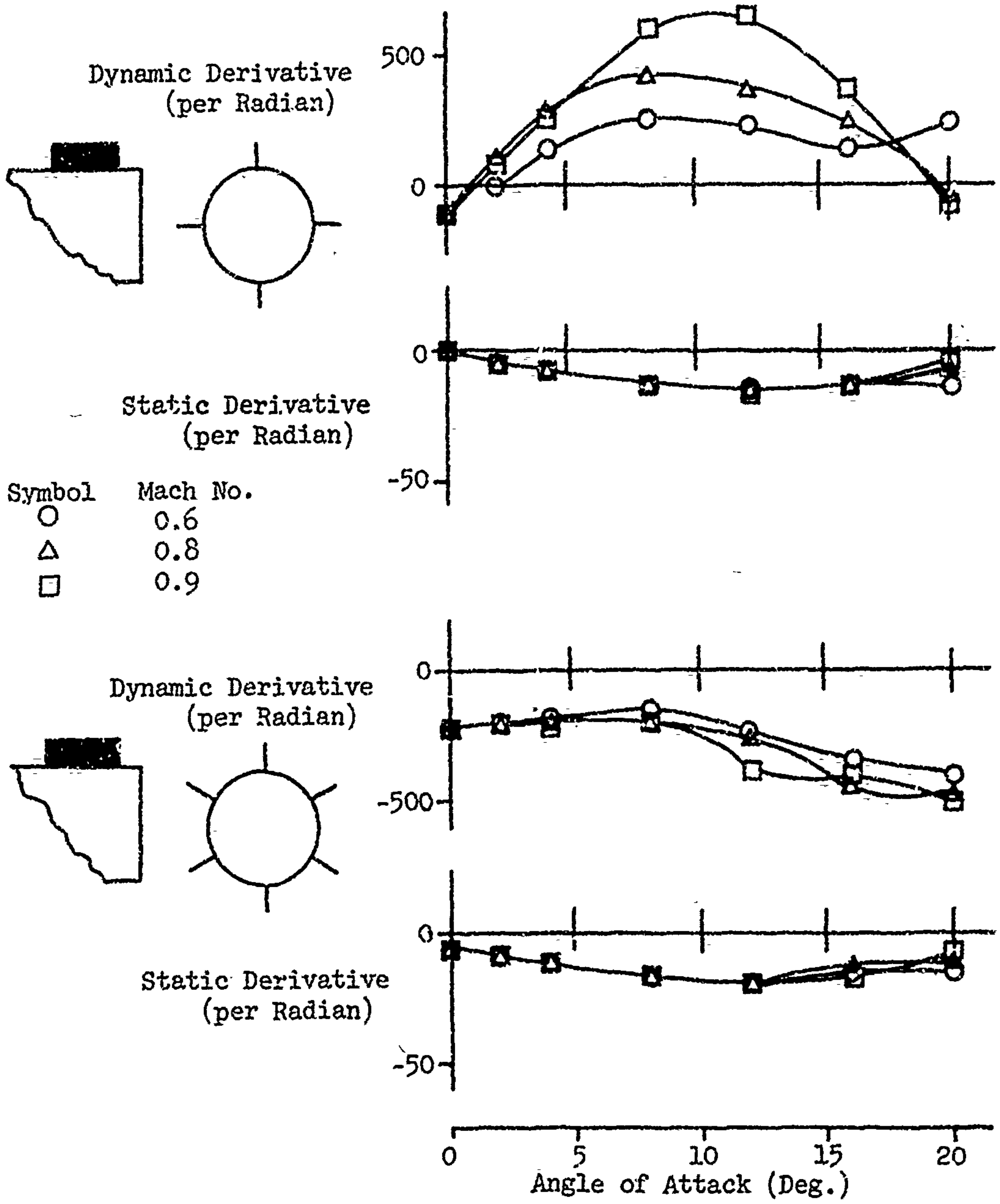


Figure 7 - D.'spenser Static and Dynamic Stability

(a) Fin Configu-ation No. 1

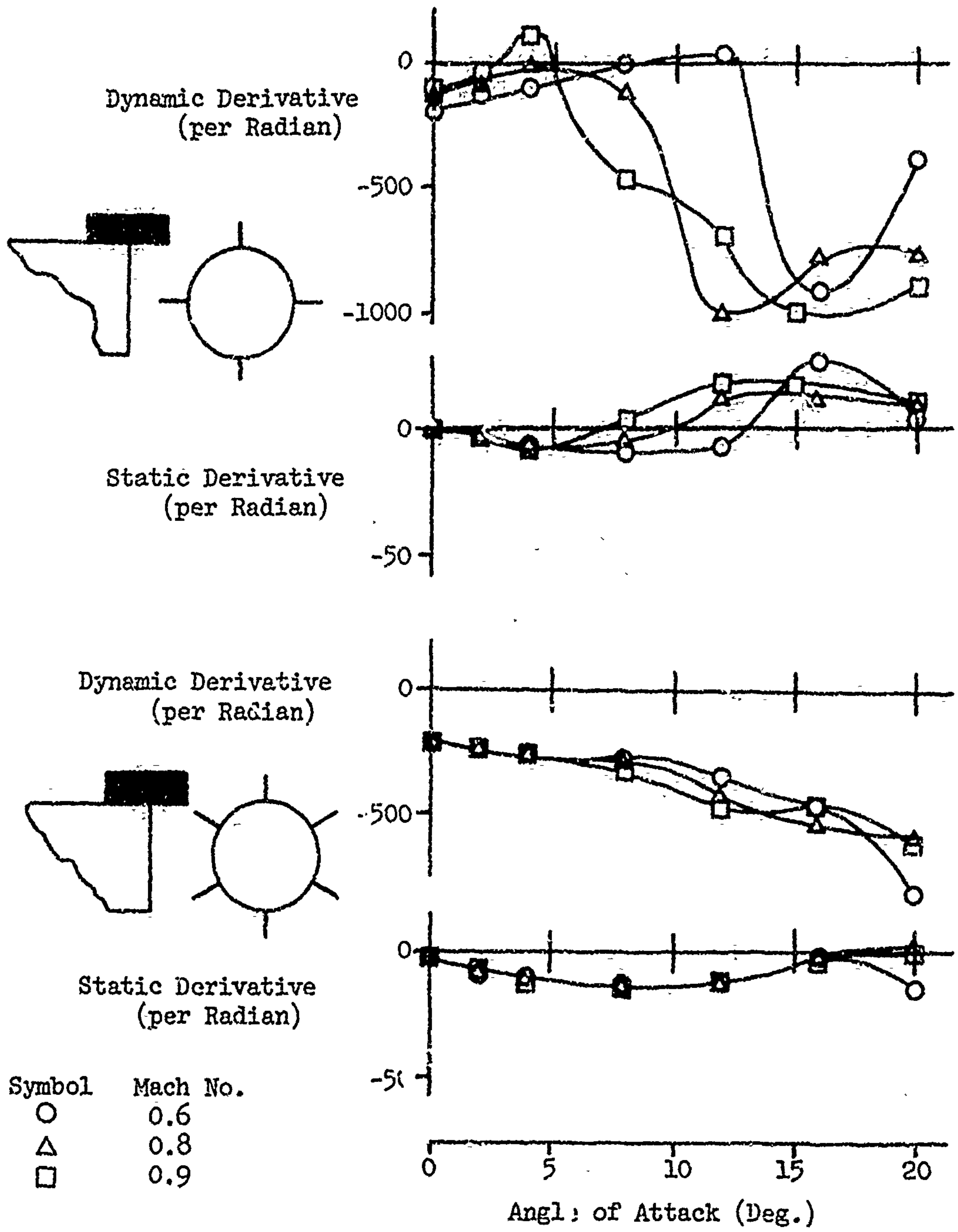


Figure 7 - Continued

(b) Fin Configuration No. 2

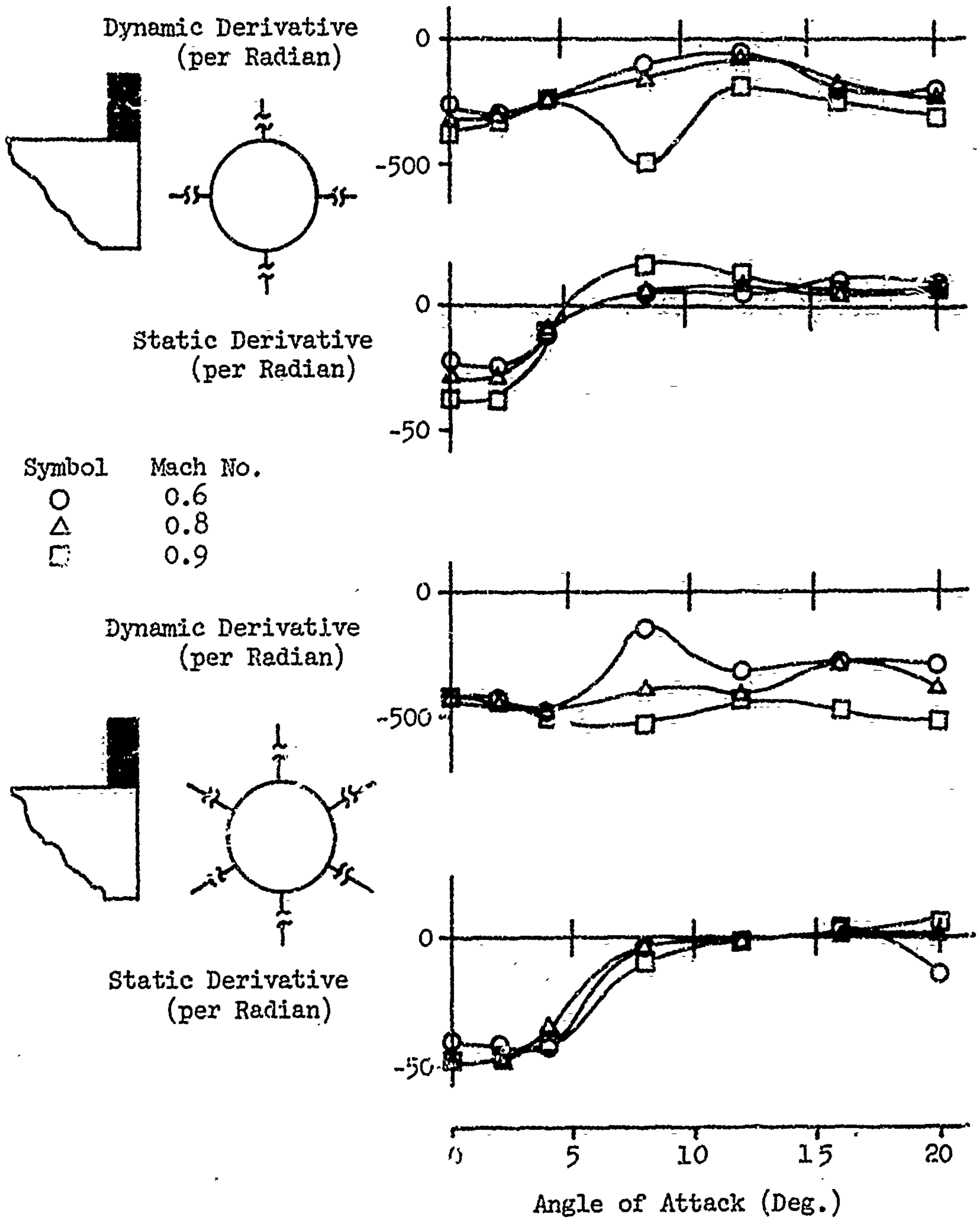


Figure 7 - Concluded

(c) Fin Configuration No. 3

Big Stick model was scaled for geometry, weight, and moment of inertia. An ejection force was applied to the model store at release to simulate ejection velocity obtainable with the Aero-7A rack. The aircraft angle of attack was adjusted for equilibrium flight for a weight of 22000 pounds. Runs simulating launch velocities of 200, 300, 400, and 475 knots were made. All separations were very smooth and unspectacular as exemplified by the 475 knot drop shown in Figure 8.

FLIGHT TESTS

Originally, four test drops were planned for the Spring of 1972 to demonstrate the concept. The first two drops had identical launch conditions to get some check of the aircraft/weapon separation, subweapon deployment, and trajectory repeatability. Vehicles three and four were to be launched from different altitudes and velocities to determine their effects on the subweapon impact distances.

Flight tests were conducted at NARF in May and June 1972. The nominal launch conditions for drops 1 and 2 were to be a velocity of 400 knots, an altitude of 5000 feet, and level flight. The actual conditions for the first drop were an aircraft velocity of 423 knots, an altitude of 5375 feet and a climb angle of 1 degree. Actual conditions for the second drop were an aircraft velocity of 430 knots, an altitude of 5472 feet and a dive angle of 1.2 degrees. In each case, the door deployed 3/4 second after launch. The weapon was launched from the centerline station of the A-4C aircraft. Weapon separation from the aircraft was the same as predicted by the dynamic model drop tests conducted in the wind tunnel. All subweapons deployed as expected. Trajectory information was obtained for the first subweapon on the first drop and for the dispenser on the second drop.

On drops number three and four, the explosive device which deploys the dispenser door did not arm upon separation from the aircraft due to the lanyard breaking during flight. Because the door was not blown off, there was no subweapon deployment and trajectory data for the 3290 pound Big Stick was obtained the hard way.

Two additional vehicles were constructed the following year. Tests were conducted in June this year at NARF. On drop number five the lanyard on the first parachute failed and separated as the chute inflated. Therefore, again the subweapons did not deploy. On drop number six, the Big Stick separated from the A-4 and deployed all the subweapons as planned; however, it was prematurely launched three minutes from the drop zone so that it was out of range of the ground data acquisition equipment. Some air-to-air photo coverage was obtained by the chase plane, however; and the subweapon ground impact pattern was obtained by a ground survey. The launch conditions were an aircraft velocity of 280 knots and an altitude of 5000 feet. The aircraft was in a 25 degree left bank. Door deployment was ten seconds after release.

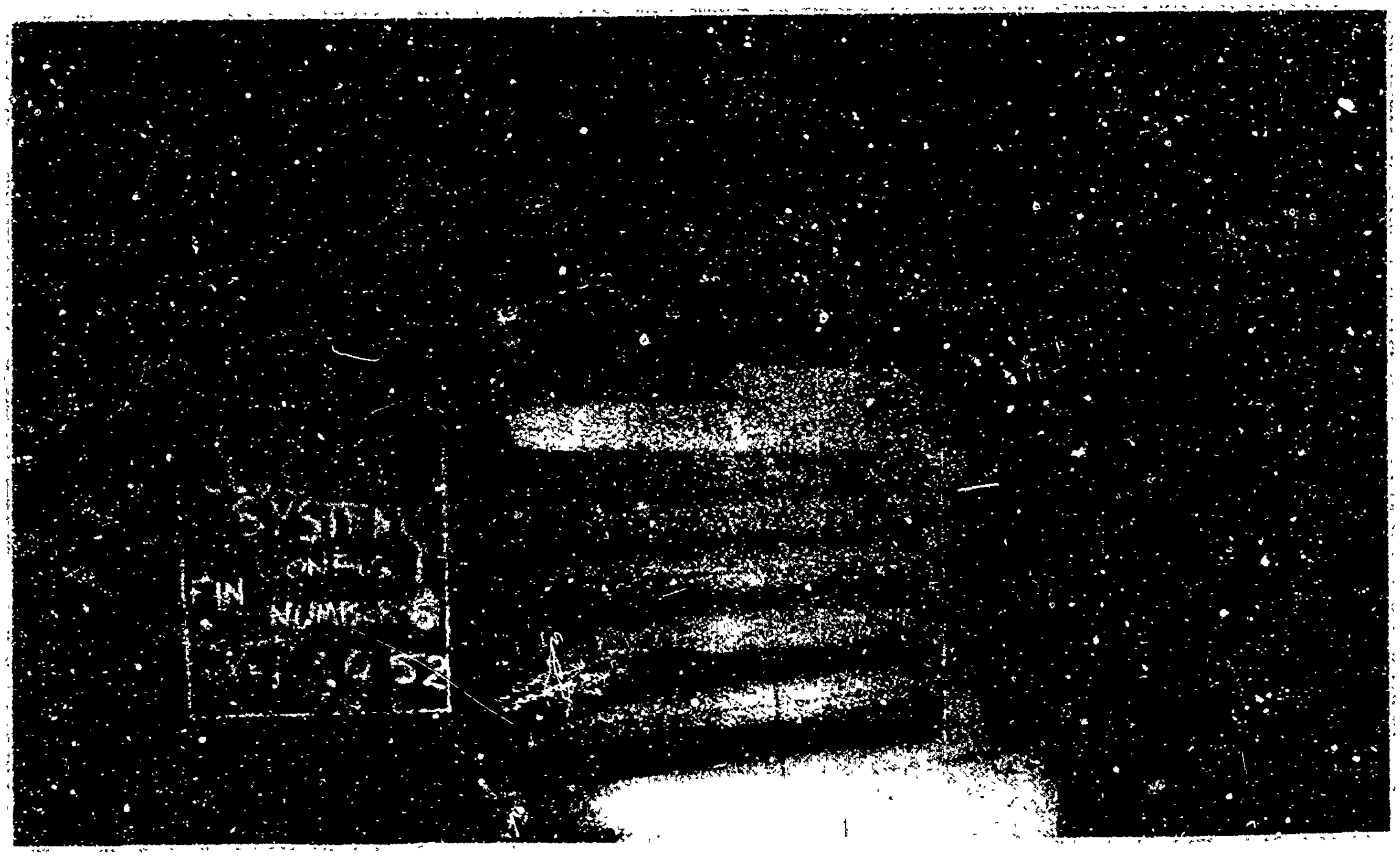


Figure 8 - Wind Tunnel Dynamic Store Separation Test

RESULTS

TRAJECTORIES

The trajectories of the subweapon and dispenser from the first two tests are shown in Figure 9. Figure 10 shows the ground impact pattern obtained from drops one, two, and six. The lower velocity and delayed door deployment on vehicle number six significantly reduced the subweapon pattern length.

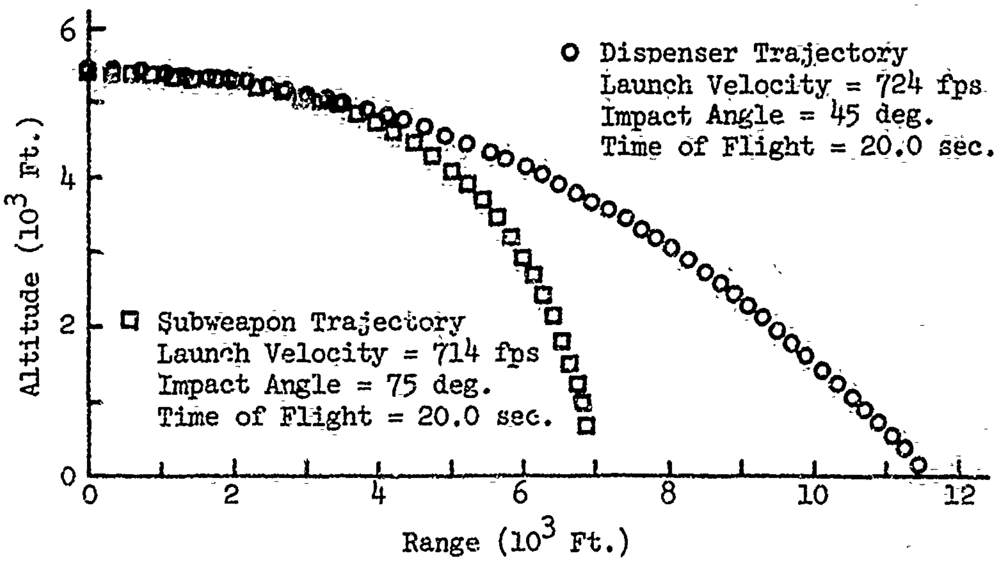
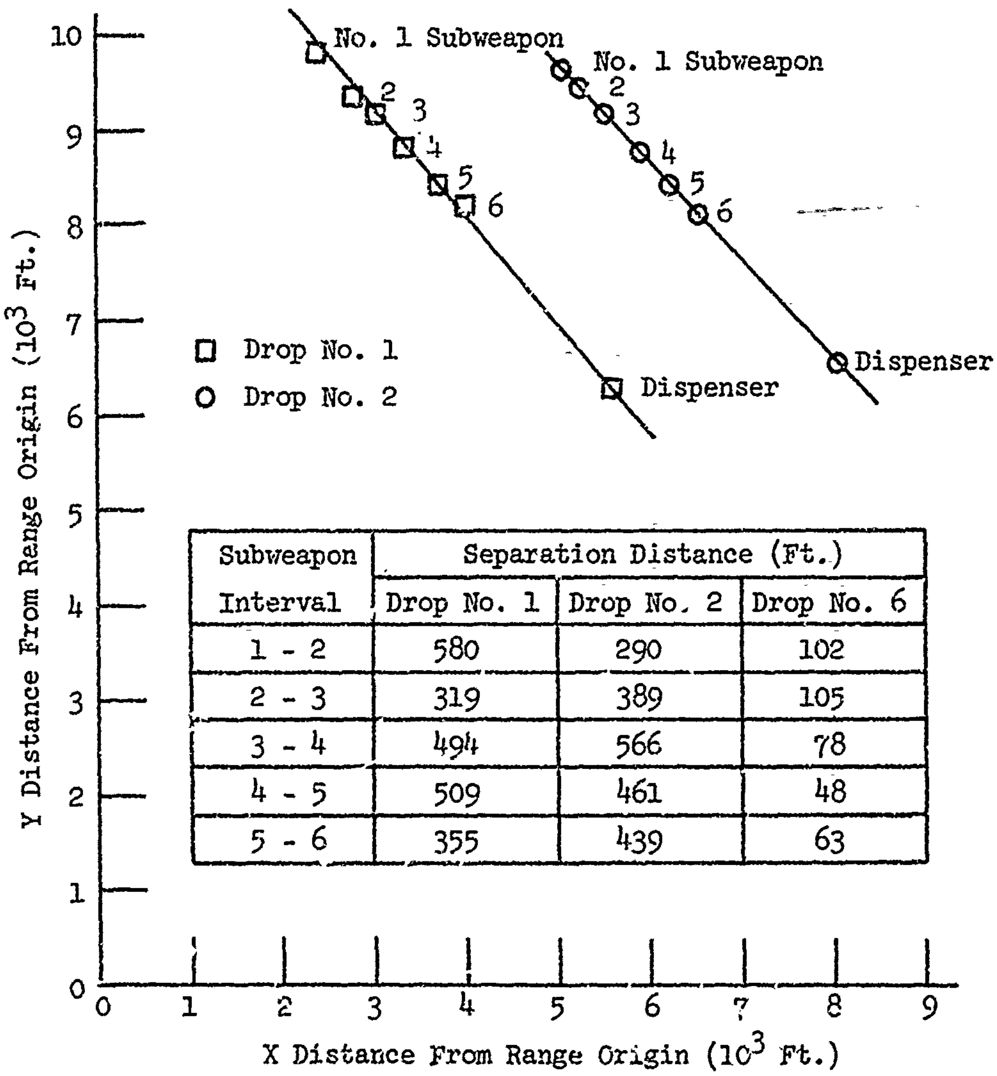


Figure 9 - Dispenser and Subweapon Trajectories

Data acquisition equipment at the Naval Aerospace Recovery Facility permitted only one object to be tracked. It was therefore necessary to calculate the trajectories of the remaining subweapons. Known boundary conditions included the velocity, angle, altitude, and time of deployment of each subweapon from the dispenser. The drag area of the dispenser and of the drogue chute-subweapon system was available from the flight tests. The drag area for the dispenser was 0.601 square feet.

A constant value of drag area was not obtained for the subweapon because of oscillation. A plot of drag area vs. time is shown in Figure 11. A simple arithmetic average and an RMS average were calculated and each of these values were used in a six degree of freedom point mass trajectory program to see which value would most closely match the actual trajectory. The calculated and actual trajectories are shown in Figure 12. A comparison shows that the arithmetic average gives the best results.



Subweapon Interval	Separation Distance (Ft.)		
	Drop No. 1	Drop No. 2	Drop No. 6
1 - 2	580	290	102
2 - 3	319	389	105
3 - 4	494	566	78
4 - 5	509	461	48
5 - 6	355	439	63

Figure 10 - Ground Impact Pattern

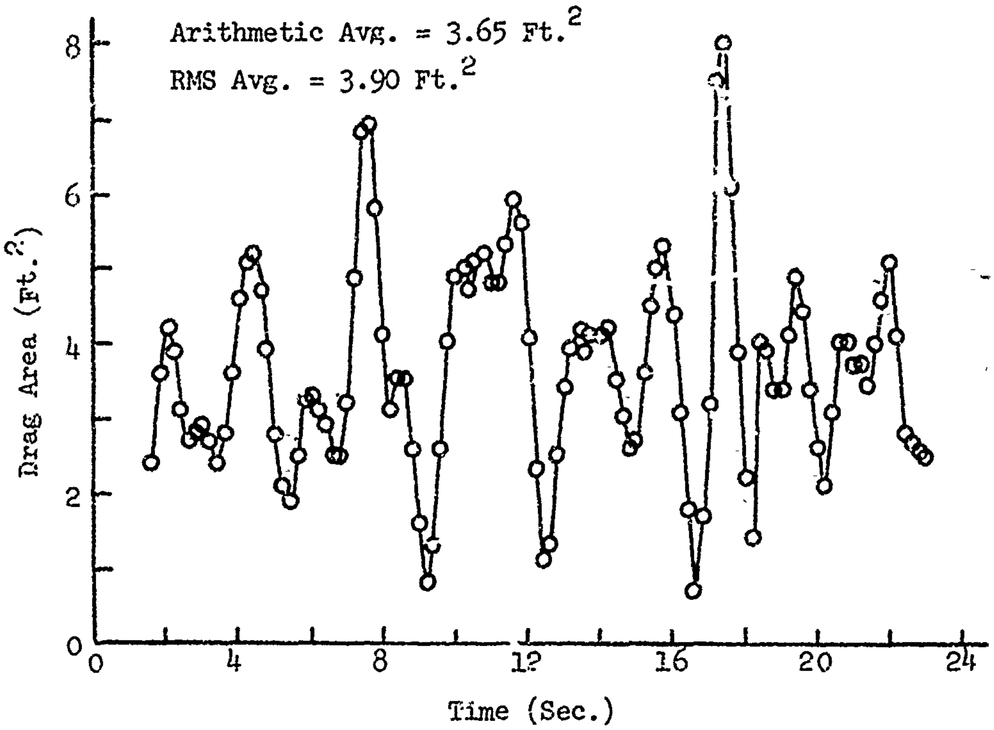


Figure 11 - Variation of Subweapon Drag Area With Time

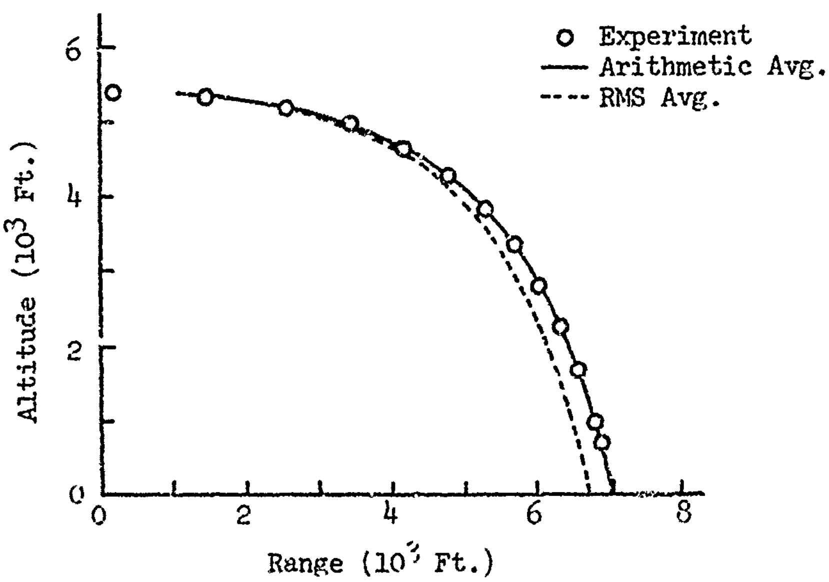


Figure 12 - Comparison of Subweapon Actual and Computed Trajectories

Figure 13 shows actual and calculated trajectories for the empty dispenser. By using the proper value of drag area, the dispenser and subweapon trajectories could be calculated quite accurately. This established a high degree of confidence in the accuracy of the calculated trajectories of the other subweapons.

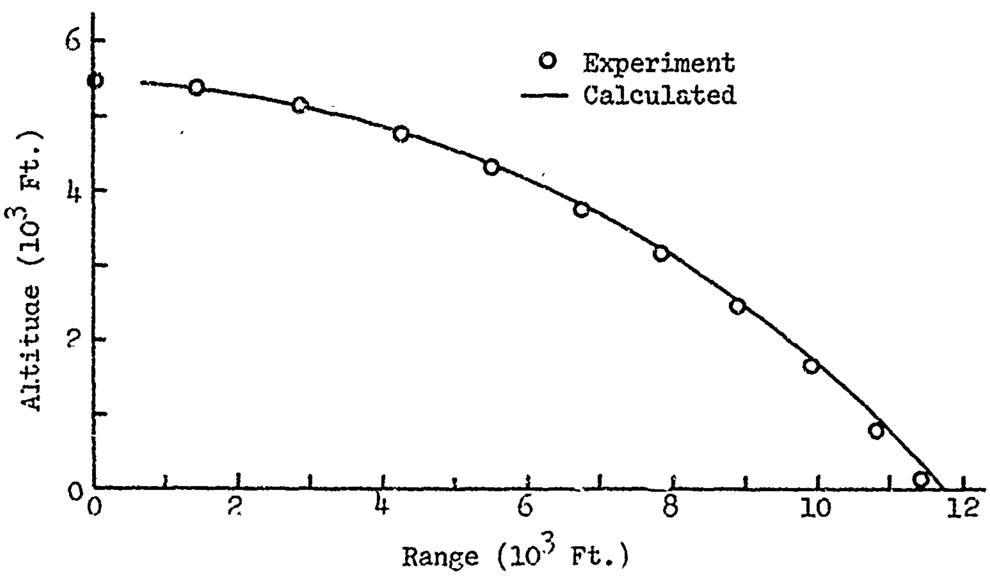


Figure 13 - Comparison of Dispenser Actual and Computed Trajectories

Using the measured aircraft velocity and altitude and actual weapon weights and drag areas, the trajectories of each of the subweapons were then calculated. These are shown in Figure 14 for drop number one and in Figure 15 for drop number two. Comparison of the trajectories in the two figures shows that the repeatability is good. The small differences are due to the slight differences in launch conditions.

A similar technique was used to fill in some of the missing gaps of data from drop number six. The aircraft speed and altitude were known as were the subweapon impact points relative to one another. It was then necessary only to iterate the time intervals between each subweapon deployment from the dispenser until a set of values was found which caused the calculated impact pattern to match that measured in the test. Drag data from the first two tests were used. Figure 16 shows the calculated trajectories and the measured impact points for drop number six.

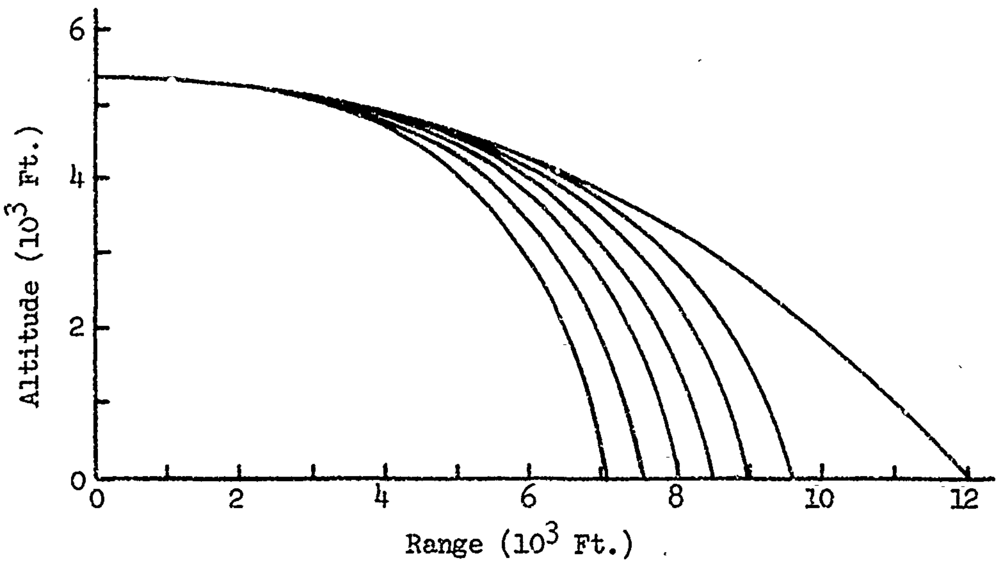


Figure 14 - Trajectories for No. 1 Drop

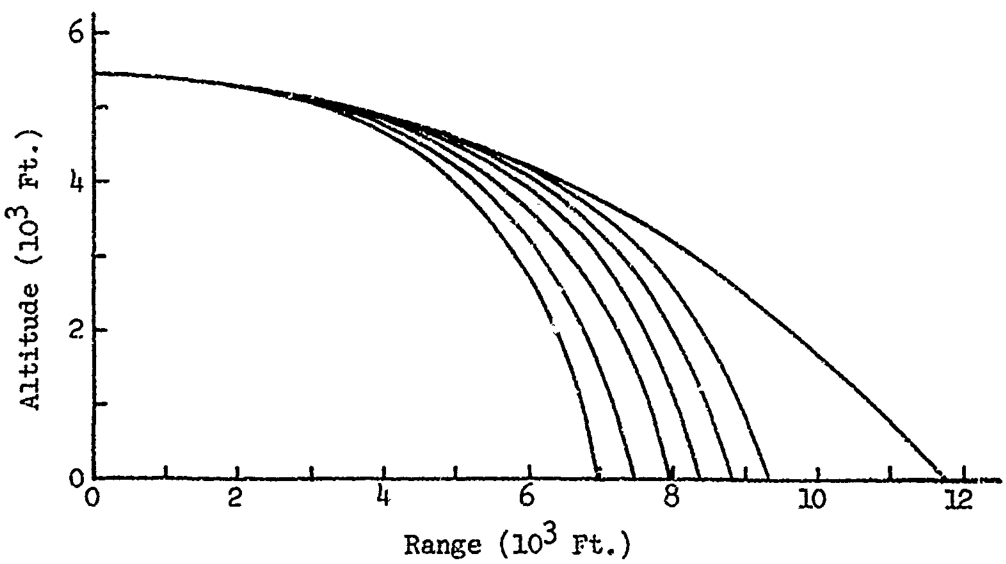
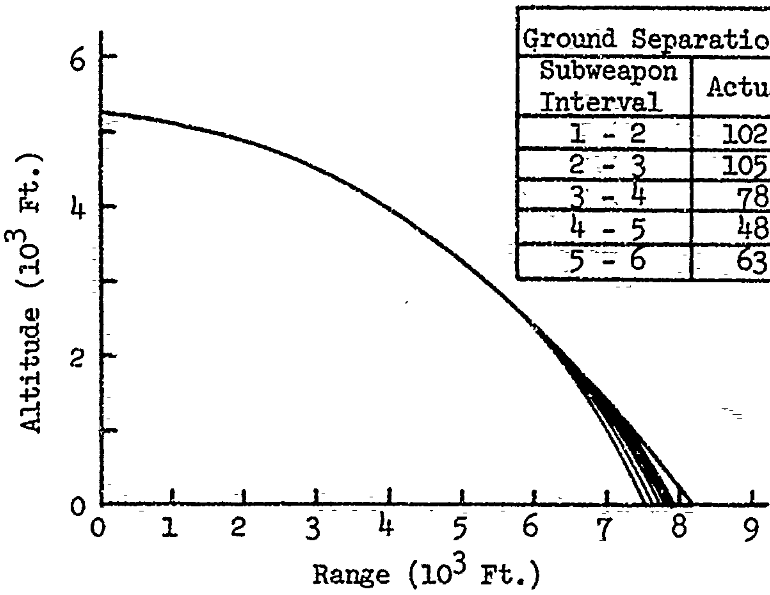


Figure 15 - Trajectories for No. 2 Drop



Ground Separation Distance (Ft.)		
Subweapon Interval	Actual	Calculated
1 - 2	102	104
2 - 3	105	102
3 - 4	78	74
4 - 5	48	49
5 - 6	63	73

Figure 16 - Trajectories for No. 6 Drop

STORE SEPARATION

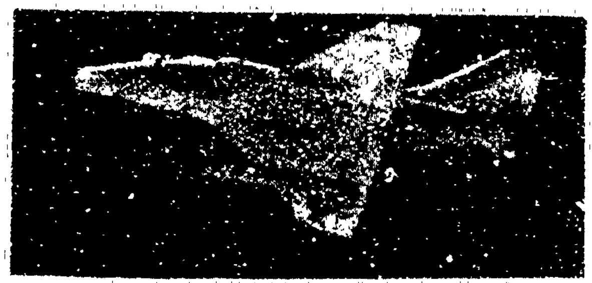
Figure 17 shows the Big Stick being ejected from the centerline station of the A-4 aircraft. It is graphically evident that the separation characteristics of this store are quite good. Examination of Figure 8 and Figure 17 gives a visual comparison of the agreement between the wind tunnel separation tests and the full scale flight test. In a qualitative sense, the agreement between the model scale and full scale tests is very good.

LAUNCH PARAMETERS

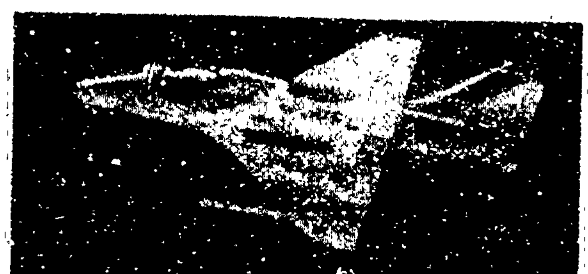
A short study was undertaken to determine the effects of launch parameters, i.e., velocity, altitude, dive angle, and door delay, on the subweapon impact pattern. Figure 18 shows the effects of velocity and alitude for dive angles of 0, and 20 degrees. Figure 19 shows the effect of dive angles of 0 and 20 degrees. Velocity and dive angle affect subweapon impact separation distance to a much greater extent than does altitude. The effect of door delay is the same as that of dive angle

To show the potential versatility of the weapon, two lofted trajectories were calculated. These are shown in Figure 20. Figure 20 (a) has a door deployment 3.0 seconds after launch so that the subweapons are deployed while the dispenser is still climbing. Figure 20 (b) shows a 30.0 second door delay so that the subweapons are deployed at about a 35 degree dive angle and 17000 feet downrange.

t = 0.095 sec.



t = 0.155 sec.



t = 0.195 sec.

t = 0.235 sec.

t = 0.295 sec.

t = 0.365 sec.

Figure 17 - Aircraft/Store Separation for Drop No. 5

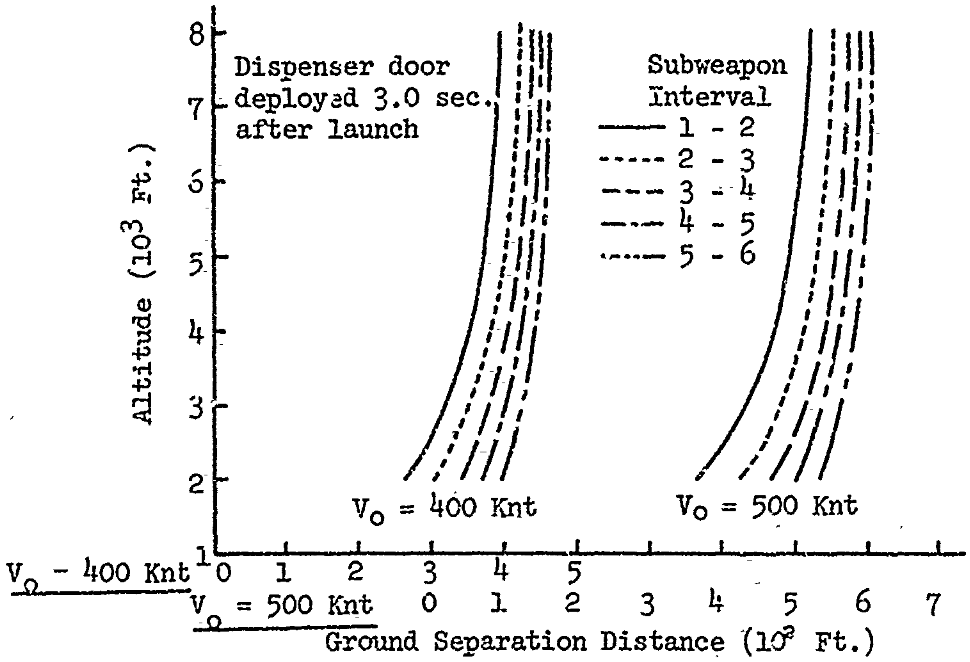


Figure 18 - Effect of Release Altitude and Velocity on Subweapon Ground Sepation Distance

(a) Zero Deg. Dive Angle

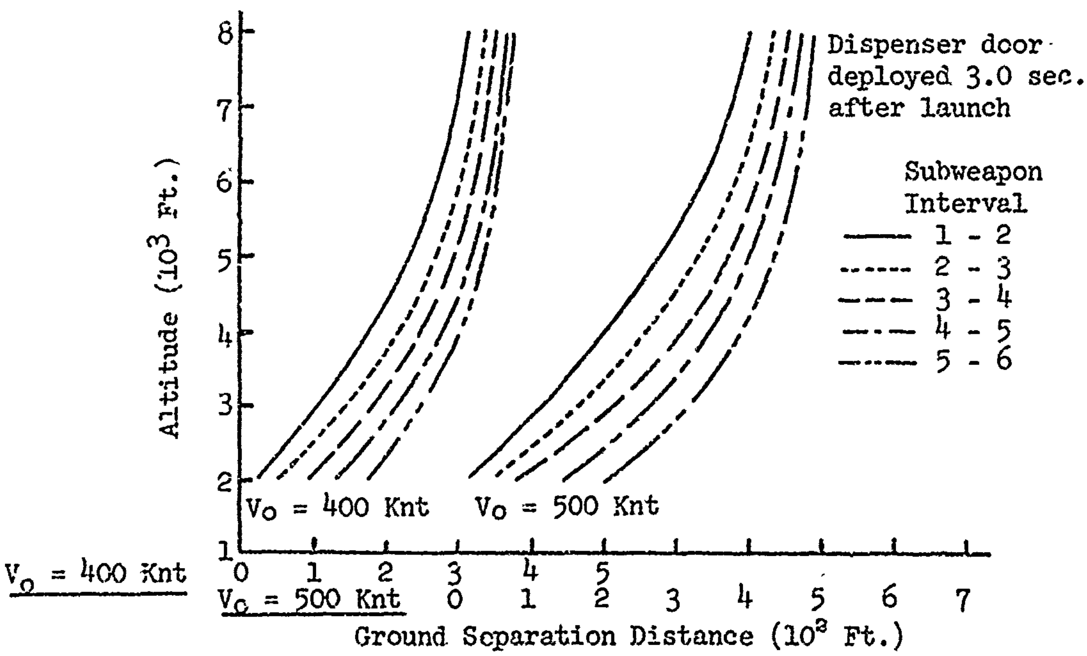


Figure 18 - Concluded

(b) 20 Deg. Dive Angle

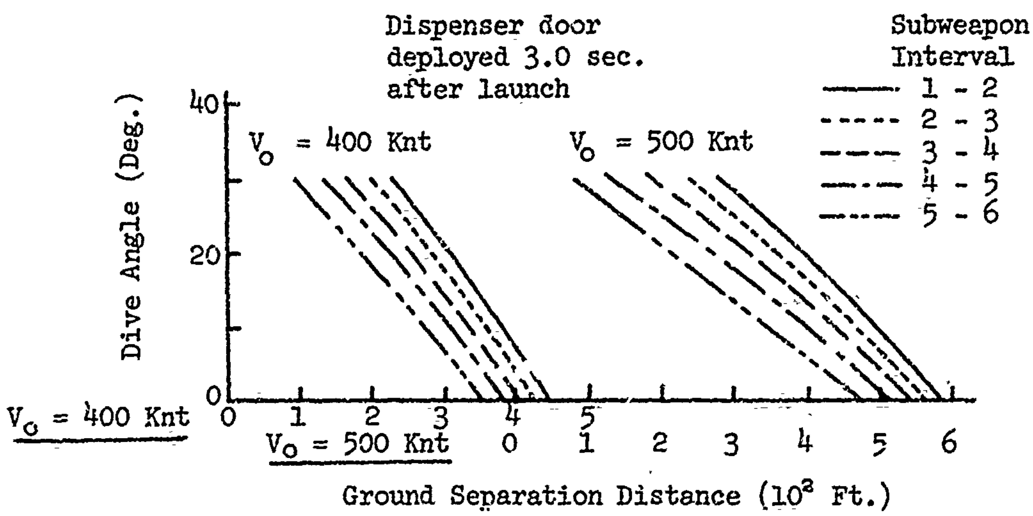


Figure 19 - Effect of Dive Angle and Launch Velocity on Subweapon Ground Separation Distance

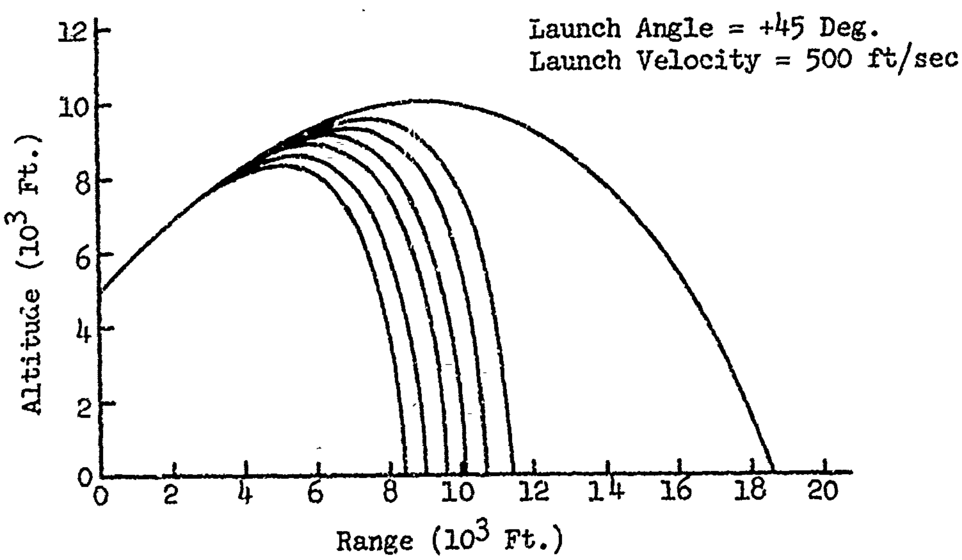


Figure 20 - Lofted Trajectory

(a) Three Second Door Delay

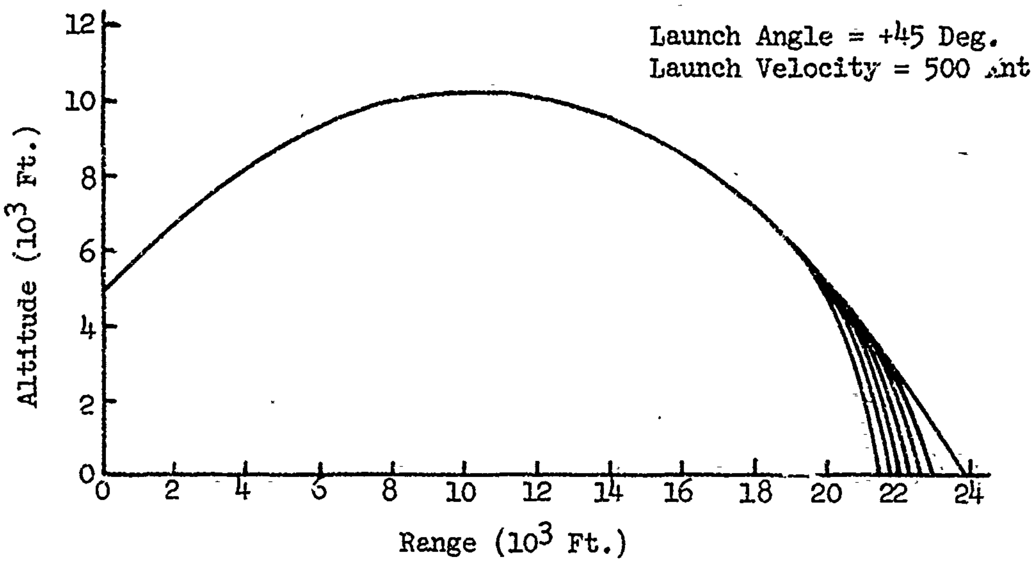


Figure 20 - Concluded

(b) 30 Second Door Delay

AIRCRAFT PERFORMANCE

A goal of this program was to reduce the captive drag of externally carried ordnance and thereby increase aircraft mission radius. Using values of drag for Big Stick measured from the flight tests and adding interference penalties for carriage aboard the aircraft, the performance of three aircraft, the A-4F, A-7A and F-4J were calculated for the close air support mission to determine how well the goal was attained. Mission radii were calculated for approximately equal loads of Mk-82's on MER's and Big Stick on each aircraft. The increase in mission radius ranges from 16.2 percent for the A-7 aircraft to 35.5 percent for the F-4 aircraft. These increases are the result of lower captive drag for the Big Stick on the outbound flight and of the absence of MER drag on the return flight. These results are shown in Figure 21.

CONCLUSIONS

It is concluded that

1. The Big Stick concept has excellent separation characteristics over a wide range of velocities.

2. Captive drag is significantly reduced over that of conventional carriage. Increases in mission radius of as much as 35 percent for the F-4J aircraft have been established.

3. Launch conditions, i.e., dive angle, velocity, altitude, and dispenser door delay time can be used to control subweapon impact patterns.

4. High density, clustered weapons can be packaged in an aerodynamically efficient package, safely ejected from the aircraft, and successfully deployed from the dispenser.

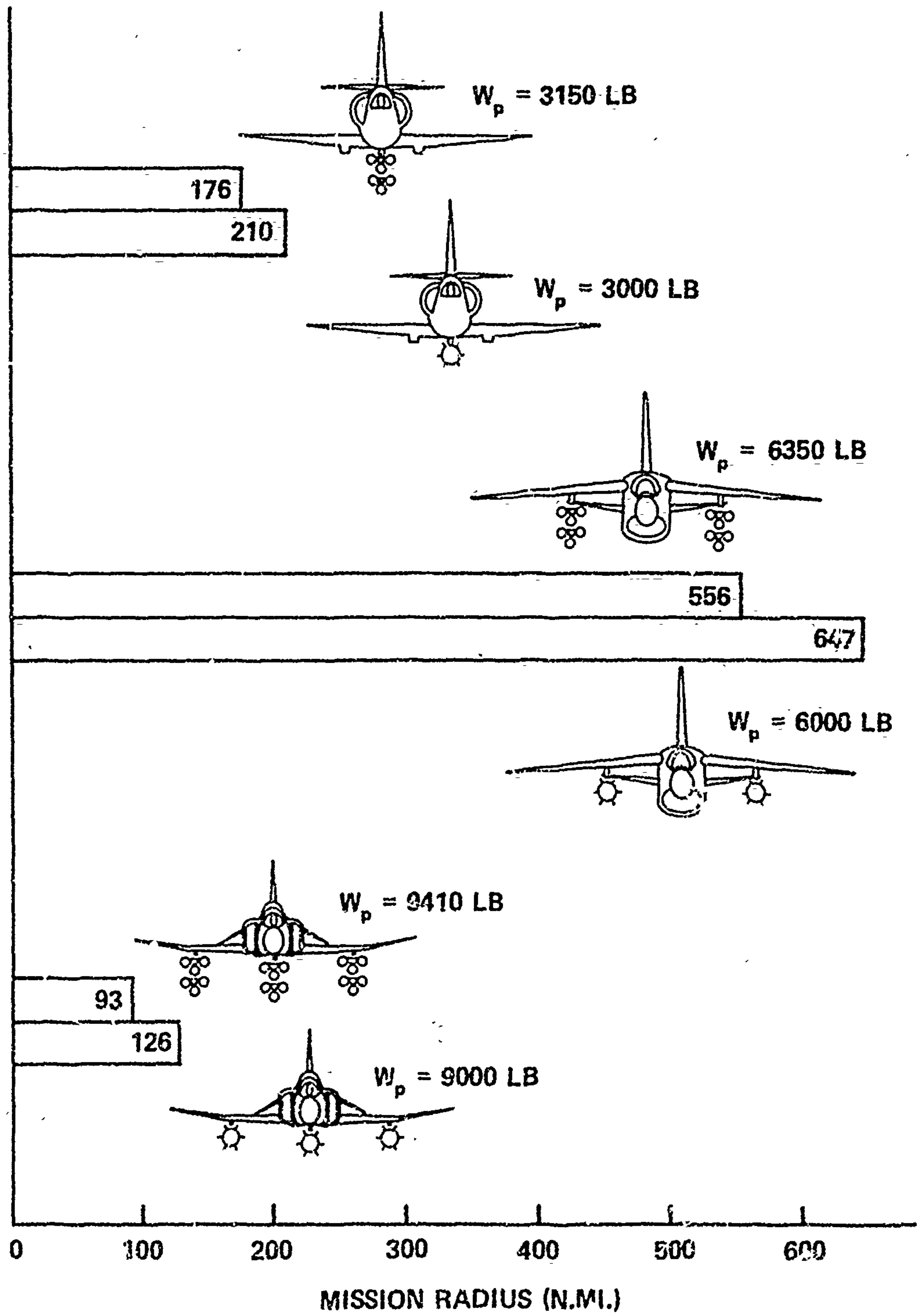


Figure 21– Close Air Support Mission Radius Comparison

AUTOBIOGRAPHY

Mr. Trobaugh attended the Florida State University and Virginia Polytechnic Institute, receiving his B.S. degree in Aerospace Engineering from VPI in 1964. He then accepted employment with Headquarters, Pacific Missile Range at Point Mugu, California. In 1965, Mr. Trobaugh accepted employment with the Naval Ship Research and Development Center where he has worked on a variety of projects including aircraft performance and preliminary design and the aerodynamics of external stores. He became project manager of the Big Stick program at NSRDC in 1970 and has continued in that role to the present time.

SESSION 2

STRUCTURAL LOADS

Chairman

Mr. W. Steeper
Naval Air Systems Command
Naval Materiel Command

AN EXPERIMENTAL INVESTIGATION OF CAPTIVE FLIGHT LOADS ON A BOMB DURING EXTERNAL CARRIAGE ON THE F-111 AIRCRAFT(1) (U)

(Article UNCLASSIFIED)

by

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ABSTRACT. (U) In the mid-1960's structural loads analyses of externally carried bombs indicated that additional information was needed to (1) verify the adequacy of wind tunnel data in predicting bomb carriage loads and (2) adequately define the distribution of aerodynamic loads on the various bomb components (nose, fins, etc.).

Sandia Laboratories has designed and flown a B43 FLU (Flight Loads Unit) in an attempt to better define bomb carriage loads by obtaining full scale flight data. This unit includes instrumentation to measure aerodynamic load distributions in addition to the total aerodynamic forces and moments.

The B43 FLU was carried on numerous F-111 flights during the aircraft Category I structural verification program at Edwards AFB during 1971 and 1972. Data collected included the FLU data (pressures, forces, strains, and accelerations) and aircraft flight parameters.

This paper discusses the design of the B43 FLU including techniques involved in the calibration. Procedures employed in determining the bomb aerodynamic force and moment coefficients and the calculation of estimates of aerodynamic forces on the bomb nose, fins and tail are described. Comparisons are made between aerodynamic

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(1) The work discussed in this paper was supported by the United States Atomic Energy Commission.

coefficients calculated from the B43 FLU and those obtained from wind tunnel tests. Some preliminary results of indicated airload distributions are also discussed.

LIST OF FIGURES

Figure 18 Aerodynamic Roll Moment Coefficient vs. Beta from Main Force Balance (Left) and Fin Force Balance (Right)

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Figure 21 Aerodynamic Yaw Moment Coefficient vs. Alpha from Main Force Balance (Left) and From Nose Plus Fin Instrumentation (Right)

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Figure 23 Aerodynamic Normal Force Coefficient vs. Alpha from Main Force Balance (Left) and From Nose Plus Fin Instrumentation (Right)

Figure 24 Aerodynamic Normal Force Coefficient vs. Beta from Main Force Balance (Left) and From Nose Plus Fin Instrumentation (Right)

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Figure 26 Aerodynamic Pitch Moment Coefficient vs. Beta from Main Force Balance (Left) and From Nose Plus Fin Instrumentation (Right)

INTRODUCTION

The approach used at Sandia Laboratories to determine captive flight loads has been to (1) use aircraft performance and maneuverability information furnished by the aircraft manufacturers to establish store inertia loads and associated aircraft angles of attack and sideslip, (2) predict store aerodynamic loads from wind tunnel tests (using superposition to combine pitch and sideslip effects), (3) use procedures similar to those outlined in MIL-A-8591 to determine lug and swaybrace loads. Loads on the nose cone, tailcan, and fins were estimated by assuming distributions of the applied loads to these areas. The basis used for approximating these distributions was principally intuitive and lacked experimental verification. Furthermore, no full scale tests were available to verify that either wind tunnel tests or the assumed superposition of effects from pitch and sideslip were valid.

The uncertainties associated with the above procedures can generally be compensated for in the design stages of a bomb through adequate factors of safety in the structural design. The problem of certifying a stockpiled weapon for a new high performance aircraft for which the weapon was not specifically designed, however, poses a more difficult problem. If the loads predicted for the new aircraft are higher than can be tolerated by the existing bomb, the performance of the aircraft may have to be significantly restricted when the weapon is carried. One possible solution to the problem of defining captive flight loads consists of actually measuring both airloads and inertia loads on a weapon shape during externally carried captive flight on an aircraft. This was accomplished with the B43 FLU (Flight Loads Unit) which is capable of measuring total applied loads on the shell of the unit, the accelerations on the unit, pressures at numerous points on the nose and tailcan and the forces on the fins. Data were recorded in an analog format on magnetic tape during all flights. The analog information was later digitized at a sample rate of 20/sec. for data reduction purposes.

GENERAL DESCRIPTION OF SYSTEM OPERATION

Five load cells and one roll moment transducer (which together constitute the main force balance), three accelerometers, thirty-two pressure transducers, and four fin force balances each of which employed four strain gauge bridges were used in the B43 FLU. Thus, fifty-seven measurements were made simultaneously. All of these information channels were telemetered to ground and recorded on magnetic tape. In order to correlate store loads with aircraft performance data which were recorded onboard the aircraft, a common IRIG B time base was recorded on both the B43 FLU tape and the aircraft performance tape. This time base was generated onboard the aircraft and telemetered to ground along with the FLU data.

Figure 1 is an illustration of the B43 FLU showing the general configuration of the device. The shell or outer shape (referred to as the suspended mass) is supported by five load cells and the roll moment transducer. The suspended mass is attached to the support beam through these transducers. The lug and swaybrace reaction points are an integral part of the main beam. Thus, the main force balance measures the airloads plus inertia loads on the suspended mass. The fin force balance assembly is attached to the suspended mass so that the fin loads are reflected in the total force balance readings. The two circular beams supporting a fin are each instrumented with two strain bridges which allow a determination of fin loads and locations of centers of pressure. Eight pressure transducers are located at four body stations (three in the nose shell and one in the tailcan) to determine pressure distributions in these areas.

The longitudinal, lateral, and normal accelerations were measured by three accelerometers (not shown in Figure 1) mounted on the support beam near the c.g. of the unit.

The central support beam of the unit was ballasted to provide inertia properties approximating those of a B43 bomb. This was done so that overall unit behavior and its effect on aircraft performance would be similar to that of the bomb.

The telemetry antenna was located on the bottom centerline of the unit. The instrumentation and amplifiers were supplied with aircraft power through a connector on the top centerline of the FLU.

MAIN FORCE BALANCE

The total loads on the suspended mass (airloads plus inertia loads) were obtained from the main force balance. The following matrix equation relates the load cell measurements to the applied loads and moments on the suspended mass.

$$\{F\} = [K]^{-1}\{L\} \qquad (1)$$

The vector $\{F\}$ represents the six applied forces and moments on the suspended mass. The vector $\{L\}$ represents the outputs of the five load cells and one roll moment transducer. The matrix $[K]$ relating forces indicated by the load cell to applied loads on the suspended mass was derived from static calibration. The procedure for generating the $[K]$ matrix proceeded as follows:

(1) An axial load was applied to the suspended mass in the positive direction and each of the load cell indications corresponding to this axial load were read and recorded.

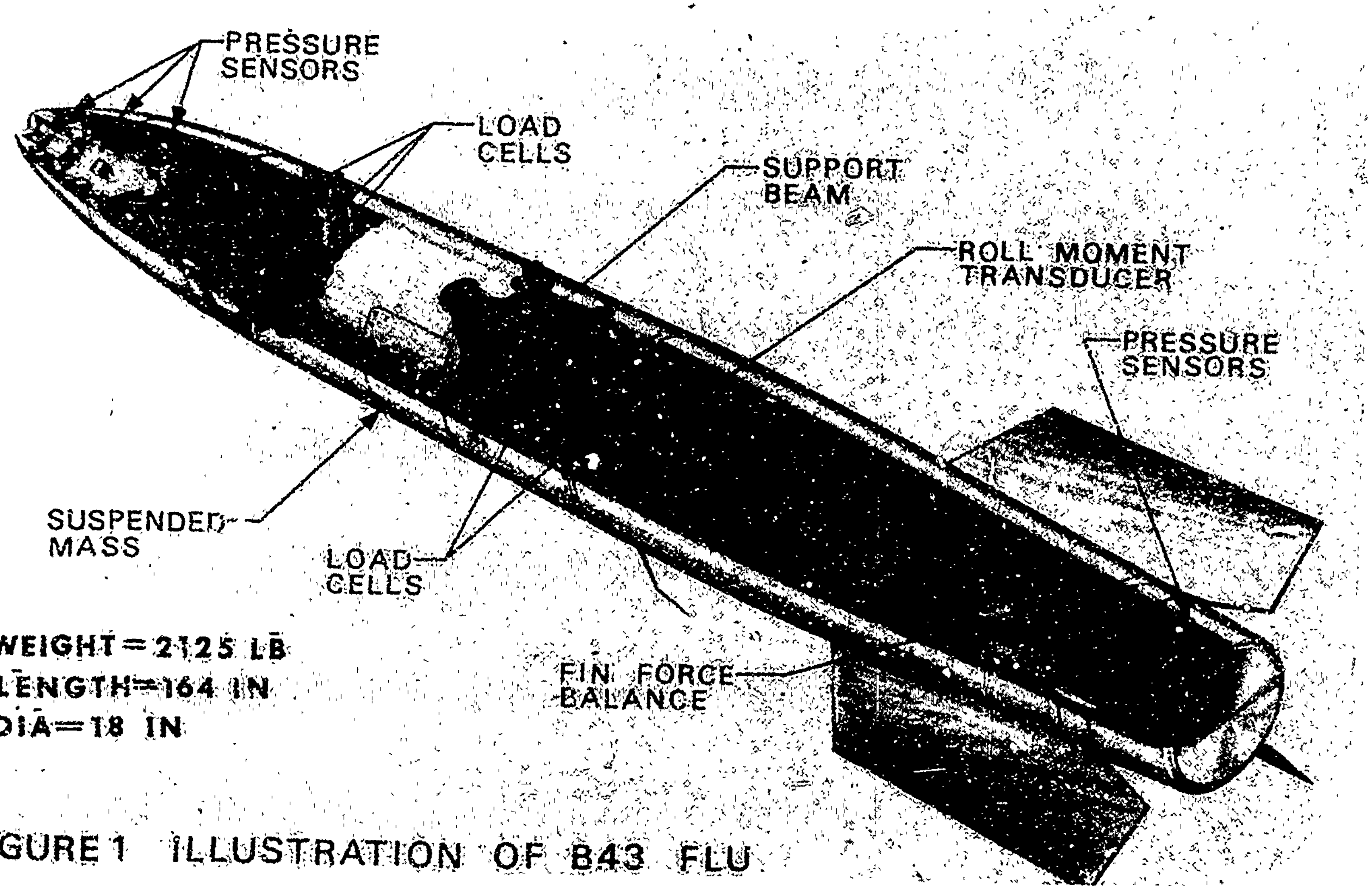


FIGURE 1 ILLUSTRATION OF B43 FLU

(2) The above procedure was repeated for three equal load increments up to a maximum calibrate value.

(3) Steps 1 and 2 were repeated for axial loads in the negative direction.

(4) Steps 1 through 3 were repeated for applied lateral load, vertical load, roll moment, pitch moment, and yaw moment.

(5) A linear least squares fit was made to the data gathered during load or moment application in a particular direction. The slope of this line in each case provided the element values for the [K] matrix.

One of the primary objectives of the B43 FLU was to determine the total applied loads on the B43 bomb during prescribed maneuvers. The main force balance, as previously stated, allows the determination of total applied loads on the suspended mass. The determination of airloads only on the store and the calculation of total loads on the actual bomb requires a knowledge of the angular velocities and linear and angular accelerations experienced by the store during the prescribed maneuvers. The linear accelerations which were used for determining inertia loads were measured on the FLU. The angular velocities and accelerations were measured on the aircraft.

In determining airloads from total loads on the suspended mass and in determining the total load on the B43 bomb, it is necessary to determine the three components of linear acceleration at the c.g. of the suspended mass of the FLU and the c.g. of the B43 bomb. Since the placement of accelerometers could not satisfy both of these conditions simultaneously (nor even one conveniently) it was necessary to determine the acceleration at desired locations from measured accelerations. The governing equation for this transformation is

$$\bar{a}_a = \bar{a}_b + \bar{\omega} \times (\bar{\omega} \times \bar{\rho}) + \dot{\bar{\omega}} \times \bar{\rho} \qquad (2)$$

where: $\bar{a}_a$ = Unknown acceleration vector at point a,

$\bar{a}_b$ = known acceleration vector at point b,

$\bar{\omega}$ = angular velocity vector,

$\bar{\rho}$ = position vector from b to a (known to unknown),

$\dot{\bar{\omega}}$ = angular acceleration vector.

Knowing the total loads on the suspended mass of the FLU and the acceleration at the c.g.'s of the suspended mass and the bomb, the airloads on the B43 shape and the total loads on the B43 bomb could be determined. To obtain airloads, the inertia loads on the suspended mass were subtracted from the total loads derived from the main force balances as follows.

$$F_{aj} = F_j - F_{Ij} \qquad (3)$$

where: F_a = Airloads on the suspended mass (B43 shape),

F = Total loads on suspended mass,

F_I = Inertia loads on suspended mass.

The subscript j pertains to the following.

j = 1 - Axial force

j = 2 - Lateral force

j = 3 - Normal force

j = 4 - Roll moment

j = 5 - Pitch moment

j = 6 - Yaw moment

To determine the total loads on the bomb, the inertia loads on the bomb were combined with the airloads on the B43 shape as follows.

$$P_j = F_{aj} + F'_{Ij} \qquad (4)$$

where: P = total loads and moments on the B43 bomb

F'_I = inertia loads on the bomb

Aerodynamic coefficients were calculated as follows for comparison with those obtained from wind tunnel data.

$$C_N = \frac{F_a}{QA} \qquad (5)$$

$$C_M = \frac{F_a}{QAL} \qquad (6)$$

where: C_N = aerodynamic force coefficient

C_M = aerodynamic moment coefficients

Q = dynamic pressure

A = characteristic area

L = characteristic length

Lug and swaybrace reactions were calculated from the applied loads in a manner similar to that specified in MIL-A-8591.

FIN FORCE BALANCE

Loads and C.P. locations on each fin were determined through the use of the Fin Force Balance illustrated in Figure 1. Each of the two circular beams to which a fin was mounted was instrumented with two strain bridges. All gauges were mounted to sense longitudinal strain. The arrangement used was sensitive to bending but insensitive to torsional and axial loads. Temperature compensation was also provided.

The fin balance was calibrated by applying known forces (in both directions) at seven predetermined locations on each fin. A multiple regression analysis was performed using the strain readings to find the constants in the following equations.

$$P = C_1 + C_2(\Delta\epsilon_F) + C_3(\Delta\epsilon_A) \tag{7}$$

$$\bar{Y} = C_4 + C_5\left(\frac{\epsilon_{1F}}{P}\right) + C_6\left(\frac{\epsilon_{1A}}{P}\right) + C_7\left(\frac{\epsilon_{2F}}{P}\right) + C_8\left(\frac{\epsilon_{2A}}{P}\right) \tag{8}$$

$$\bar{X} = C_9 + C_{10}\left(\frac{\Delta\epsilon_A}{\Delta\epsilon_F + \Delta\epsilon_A}\right) + C_{11}\left(\frac{\Delta\epsilon_A}{\Delta\epsilon_F}\right) + C_{12}\left(\frac{\Delta\epsilon_A}{P}\right) + C_{13}\left(\frac{\Delta\epsilon_F}{F}\right) \tag{9}$$

where:

P	= Fin normal force
$\bar{Y}$	= C.P. location measured from FLU center line
$\bar{X}$	= C.P. location measured from FLU nosetip
ϵ	= strain reading
$\Delta\epsilon$	= Difference in strain indicated by the two bridges on a support beam
$C_j (j=1,13)$	= Constants determined from linear regression analysis

Subscript 1 refers to inner strain bridge position on support beam

Subscript 2 refers to outer strain bridge position on support beam

Subscript F refers to forward support beam

Subscript A refers to aft support beam

After determining the constants C_j, the resulting equations were applied to the strain measurements obtained during calibration tests. Table I gives a summary of the maximum errors experienced in trying to predict the known forces and force locations.

PRESSURE TRANSDUCERS

Pressure transducers were attached to the suspended mass at three locations on the nose (stations 10, 20, and 30) and at station 160 on the tailcan. Each of the eight equally spaced transducers at each of the four body stations sensed pressure normal to the surface of the skin.

The pressure transducers were used to estimate airloads distributions on the nose and tailcan. The longitudinal pressure distribution from station 0.00 to station 10.0 was assumed to be constant and equal to the circumferential distribution at station 10.0. The same was true from station 30.0 to station 45.0. Between stations 10.0 and 20.0 and stations 20.0 and 30.0 the pressure was assumed to vary linearly. The assumed circumferential distribution of pressure was as shown in Figure 2.

Longitudinally, the nose and tailcan were divided into 1 inch ring segments. The lateral and normal components of force on each ring segment were obtained as follows.

$$F_{yi} = \{(P_7-P_3) + [(P_6-P_2) + (P_8-P_4)] \sin 45°\}A \qquad (10)$$

$$F_{zi} = \{(P_5-P_1) + [(P_6-P_2) + (P_4-P_8)] \sin 45°\}A \qquad (11)$$

where A is the chord length corresponding to the 45 degree arc over which a constant pressure is assumed to act multiplied by the 1.0 inch length of ring, F_{yi} is the net horizontal force on a 1 inch ring segment, and F_{zi} is the net vertical force on a 1 inch ring segment.

The total horizontal and vertical airloads on the nose are found from

$$F_y = \sum_{i=1}^{n} F_{yi}$$
$$F_z = \sum_{i=1}^{n} F_{zi} \qquad (12)$$

Similarly, the moments about a particular point can be found from

Table I - Maximum Errors Obtained in Predicting Calibration Loads and Load Locations from Measured Strain Output

Fin No.	Load Direction*	Max Error in Load (%)	Max Error in $\bar{x}$ (in.)	Max Error in $\bar{y}$ (in.)
1	+	6.7	0.61	0.61
1	-	5.3	0.46	0.30
2	+	5.5	0.67	0.40
2	-	3.5	0.42	0.18
3	+	6.8	0.34	0.61
3	-	1.5	0.43	0.18
4	+	2.8	0.56	0.19
4	-	3.1	0.75	0.26

*A positive load on a fin produces a clockwise roll moment on the B43 FLU looking forward.

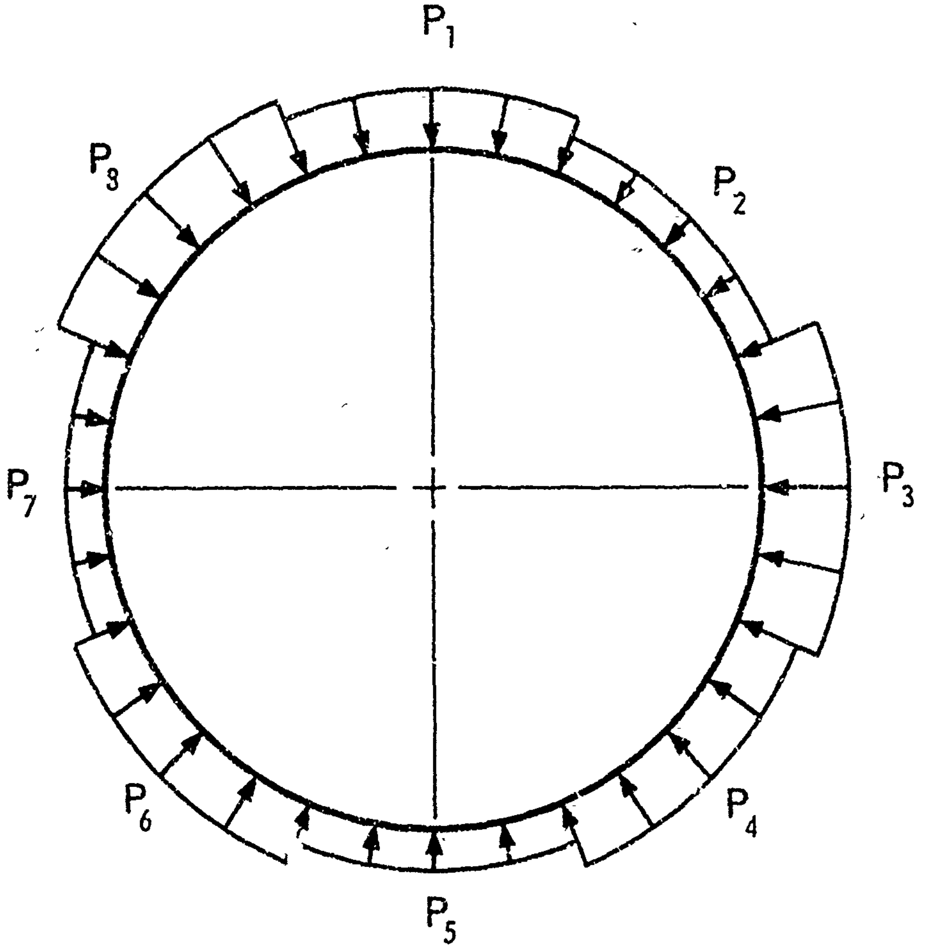


FIGURE 2 ASSUMED CIRCUMFERENTIAL PRESSURE DISTRIBUTION

$$M_y = \sum_{i=1}^{n} F_{zi}\bar{x}_i$$

$$M_z = \sum_{i=1}^{n} F_{yi}\bar{x}_i \tag{13}$$

where: n = The total numbers of 1 in. ring segments in the nose,

M_y = Pitch moment due to nose airload,

M_z = Yaw moment due to nose airload,

and $\bar{x}_i$ = Distance from 1 in. ring segment to point about which moment is to be found.

Because pressure transducers were located at only one station in the tailcan, the pressure was assumed constant from station 157.0 to station 164.0. The tailcan has a variable diameter, however, and the effect of the varying area had to be determined. The pressure loading on the tailcan was treated in the same way as the pressure loading on the nose. The previous equations developed for net forces and moments on the nose were therefore used for the tailcan loads.

RESULTS

VARIATION OF LOADS WITH TIME

In order to illustrate how external store loads vary with time, a few data samples are shown.

Figure 3 shows roll moment variation during a rolling pullout maneuver. The two curves shown give total (airload + inertia) roll moment and roll moment due to airload only. It is difficult to distinguish the individual curves as results are essentially identical.

Figure 4 shows side force and yaw moment variation during a rolling pullout. Some difference between total side force and aerodynamic side force can be seen. Since yawing moment is essentially all airload, total load and airload only curves appear as a single curve.

Figure 5 shows the normal force and pitching moment variation during a rolling pullout. Total normal force is mostly due to bomb inertia. Pitching moment due to airloads appears more significant in this particular case.

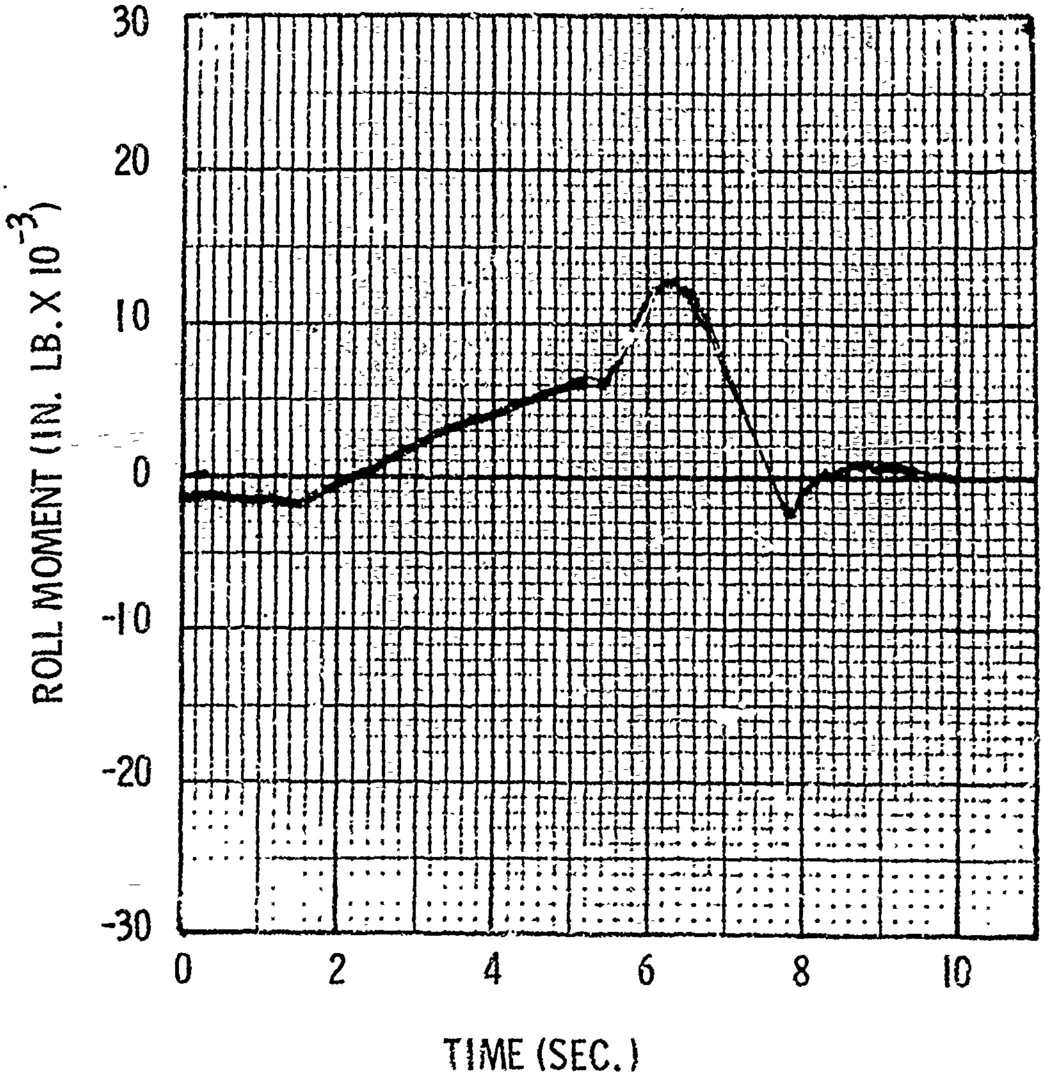


FIGURE 3: TOTAL ROLL MOMENT AND ROLL MOMENT DUE TO AIRLOAD DURING 4.5g ROLLING PULLOUT AT MACH = 1.05

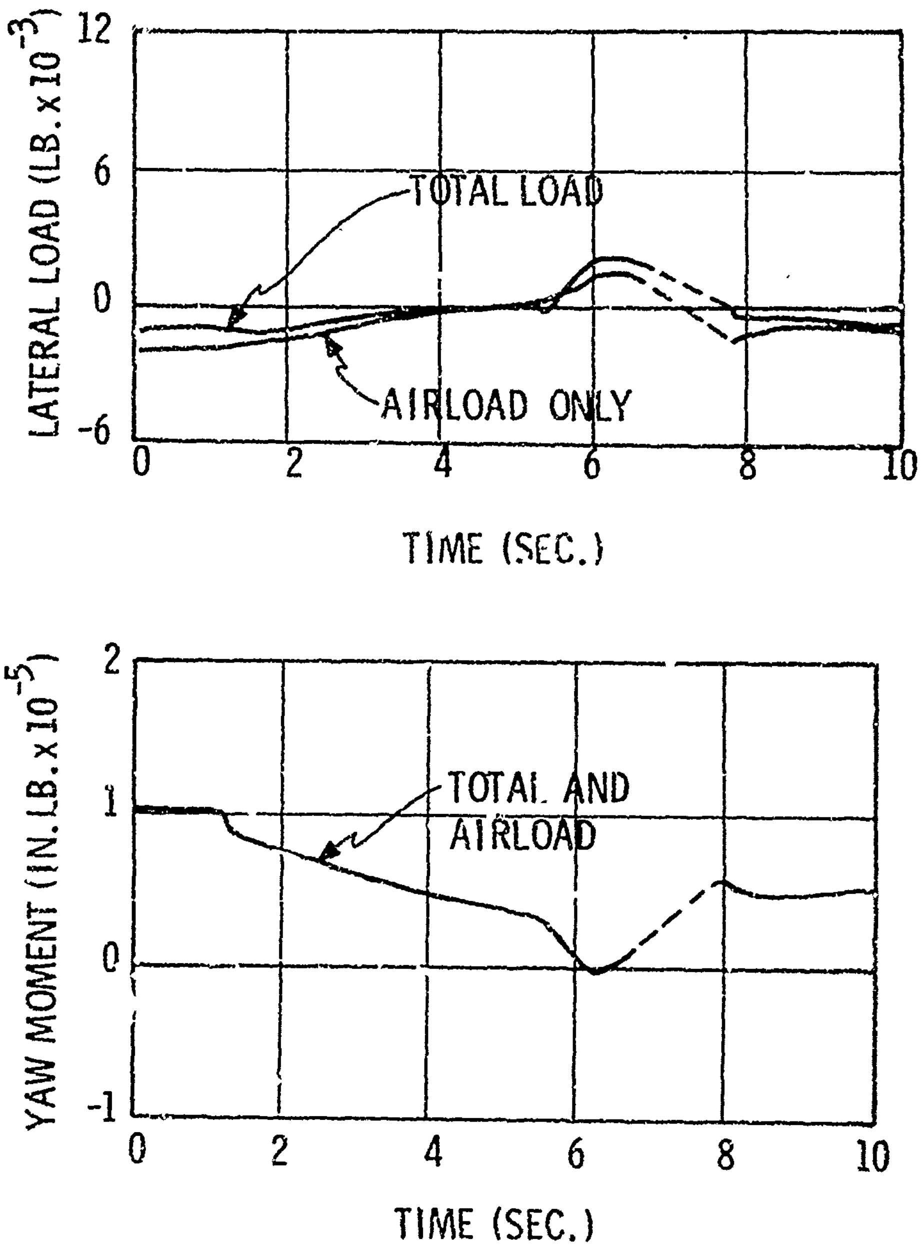


FIGURE 4: LATERAL FORCE AND YAW MOMENT VS. TIME DURING 4.5g ROLLING PULLOUT AT MACH = 1.05

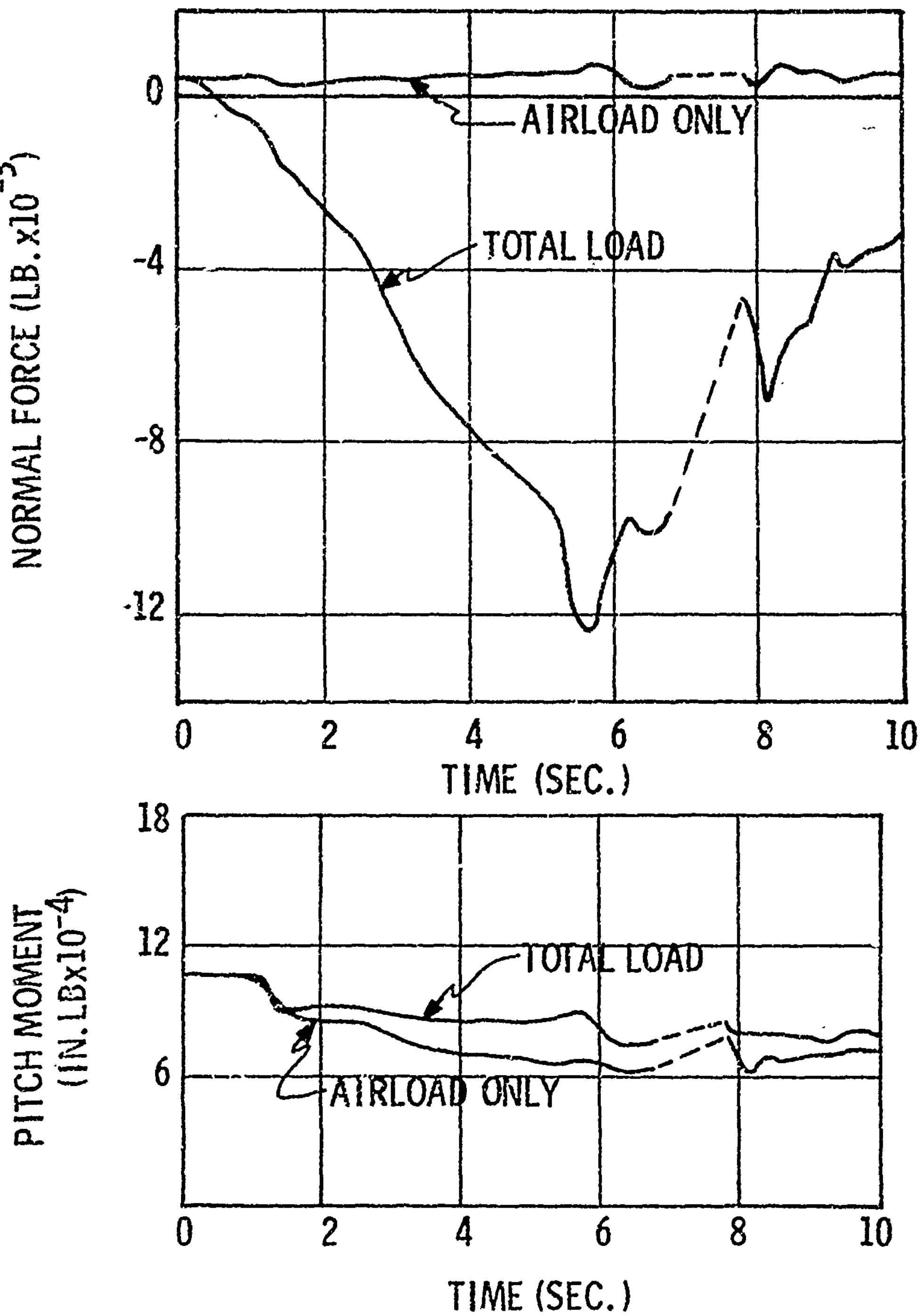


FIGURE 5: NORMAL FORCE AND PITCH MOMENT VS. TIME DURING 4.5g ROLLING PULLOUT AT MACH = 1.05

Figure 6 shows the vertical reaction at the forward suspension lug calculated for two assumed distributions of bomb yawing moment. Also shown in this figure is an example of the variation of normal fin force with time.

The dashed portions of the curves in the above figures represent data which was eliminated because it was judged excessively noisy.

COMBINED RESULTS FROM ALL MANEUVERS

In order to obtain the most usable conclusions from the B43 FLU tests, it was necessary to combine data from all maneuvers where carriage configuration, aircraft wing sweep, and Mach number were the same. This approach was chosen so that variations with angle of attack and sideslip could be studied. Subsequent graphs will present samples of the combined data.

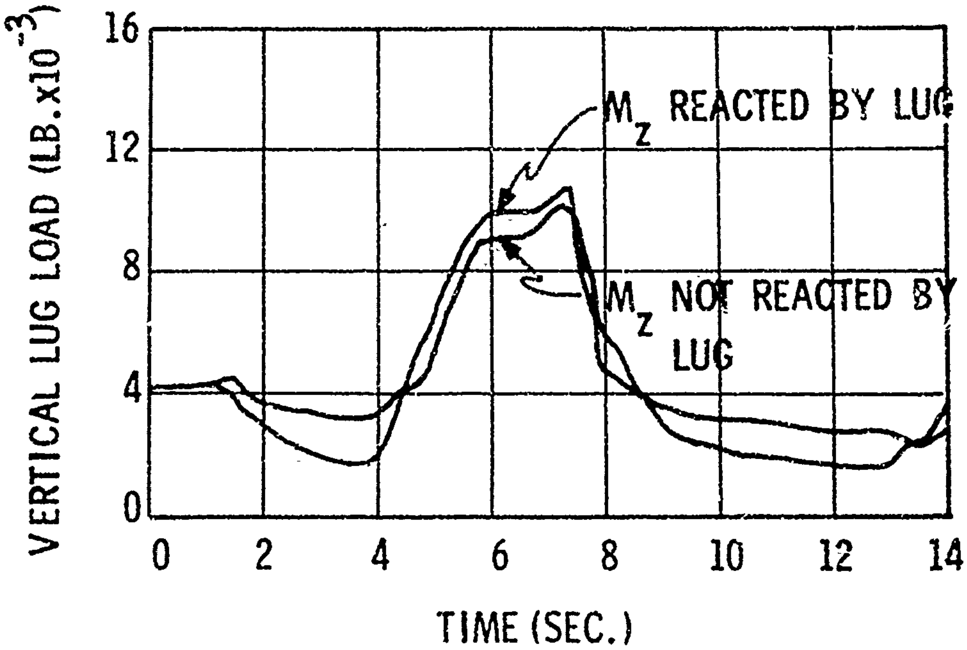
Before discussing the combined data, however, it is necessary to recognize the limitations (or general scope) of results obtained. The FLU was carried "piggyback" during a structural verification flight test program of the F-111A aircraft. Flight conditions were primarily selected to verify analytical studies of aircraft loading caused by external stores rather than to demonstrate full maneuver capability of the aircraft or to obtain worst store environments. Thus the range of angles of attack and sideslip are somewhat limited. For example, angle of sideslip is generally less than 5 degrees (limited to 2 degrees for some carriage configurations).

Comparison of Airload to Total Load from FLU Tests

Figures 7 through 11 present ratios of aerodynamic load to total (airload + inertia) load plotted versus angle of attack (ALPHA) and angle of sideslip (BETA). Although only one carriage configuration is covered by the plots, similar plots for other configurations suggest the following general conclusions.

When the ratios are equal to 1.0, all load is due to airload. This case seems to be generally true for all moment ratios (AMX/MX, AMY/MY, AMZ/MZ) and for the side force ratio (AFY/PY). At higher maneuver conditions (i.e., higher acceleration conditions) this general trend might be slightly modified.

When the ratios are equal to 0.0, all load is due to inertia. This case seems to be generally true for the vertical force ratio (AFZ/PZ). Thus, airloads have little effect on the magnitude of vertical force.



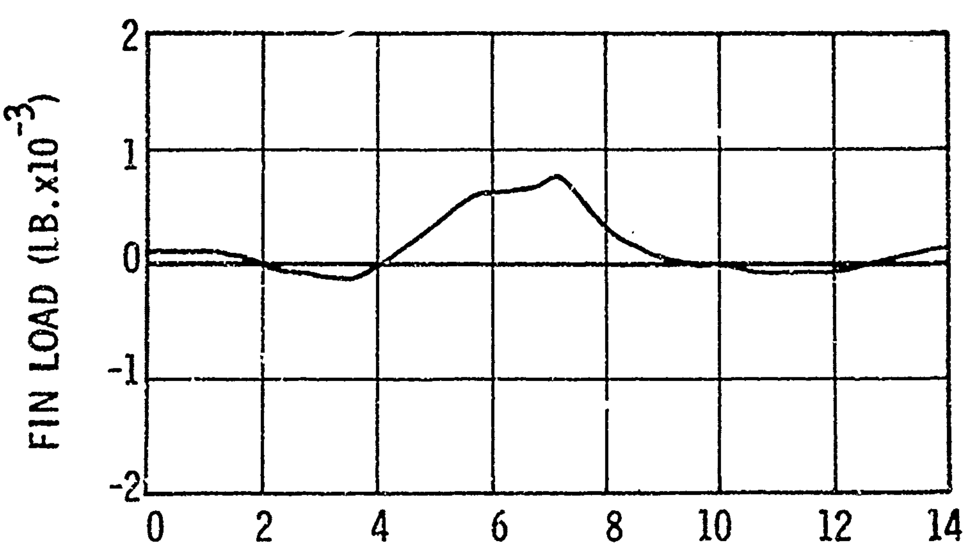


FIGURE 6: VERTICAL LUG LOAD AND FIN LOAD VS. TIME DURING 5g ROLLER COASTER MANEUVER AT MACH = 1.05

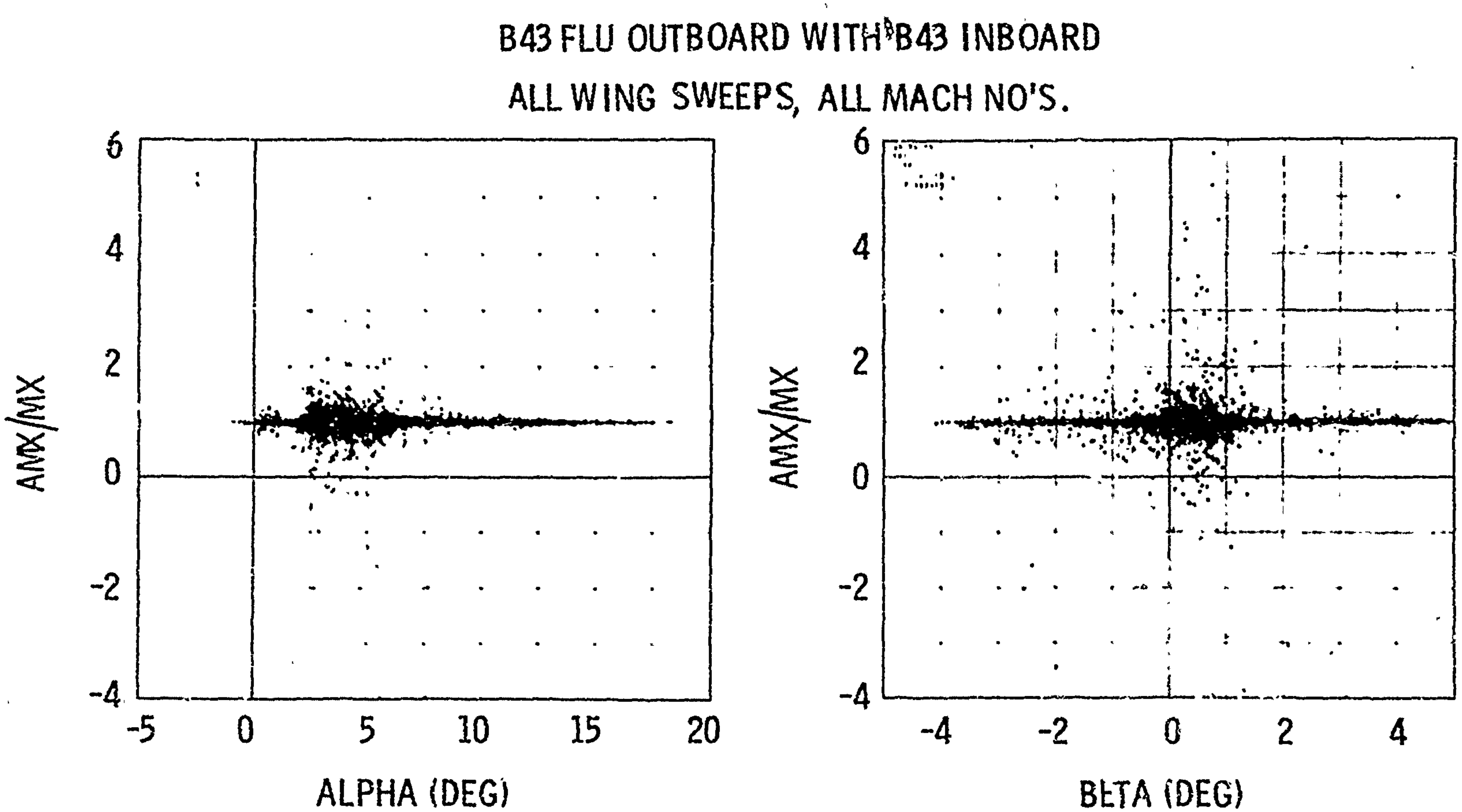


FIGURE 7: RATIO OF AERODYNAMIC ROLLING MOMENT TO TOTAL ROLLING MOMENT VS. ALPHA AND BETA.

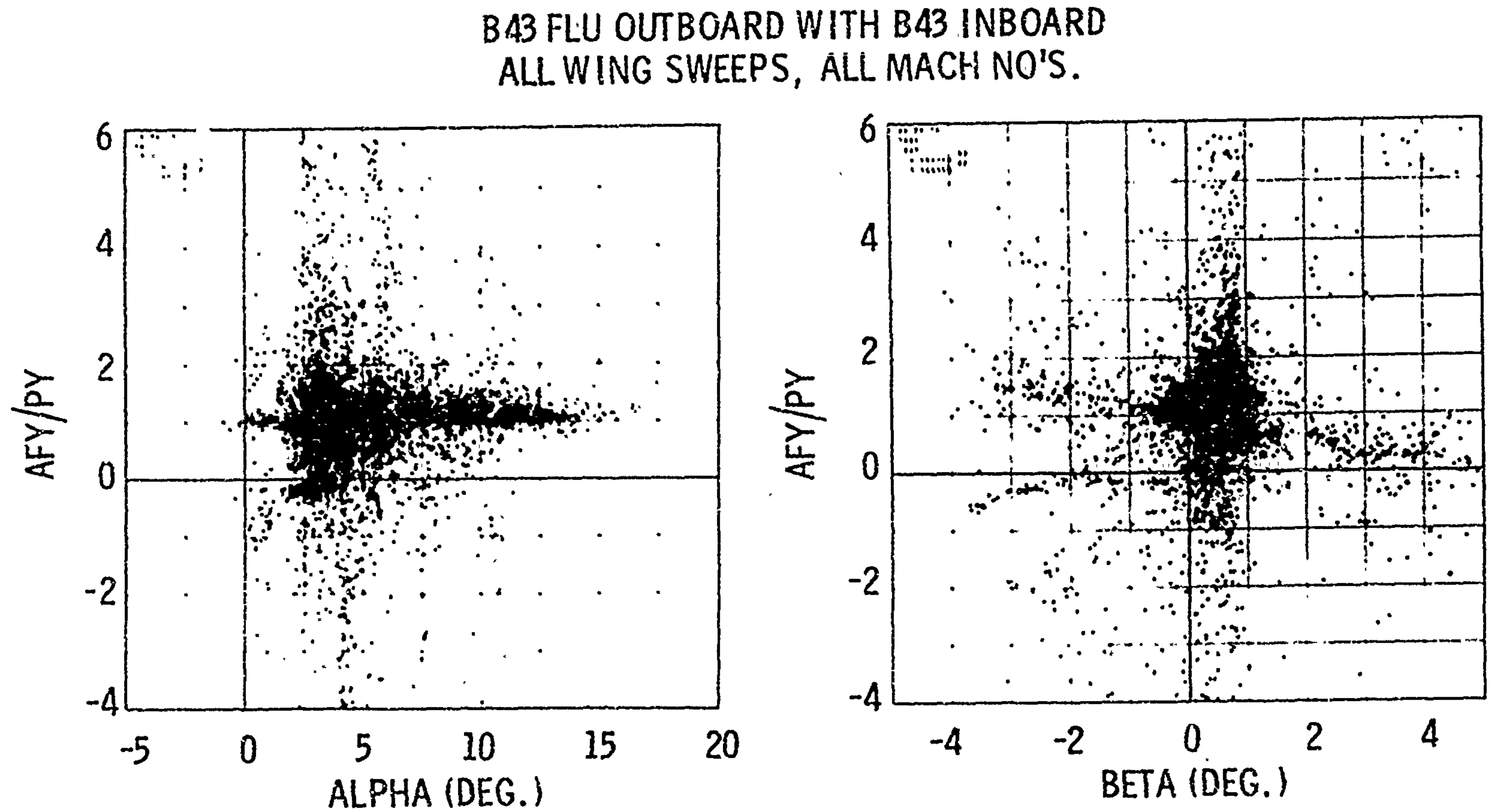


FIGURE 8: RATIO OF AERODYNAMIC SIDE FORCE TO TOTAL SIDE FORCE VS. ALPHA AND BETA

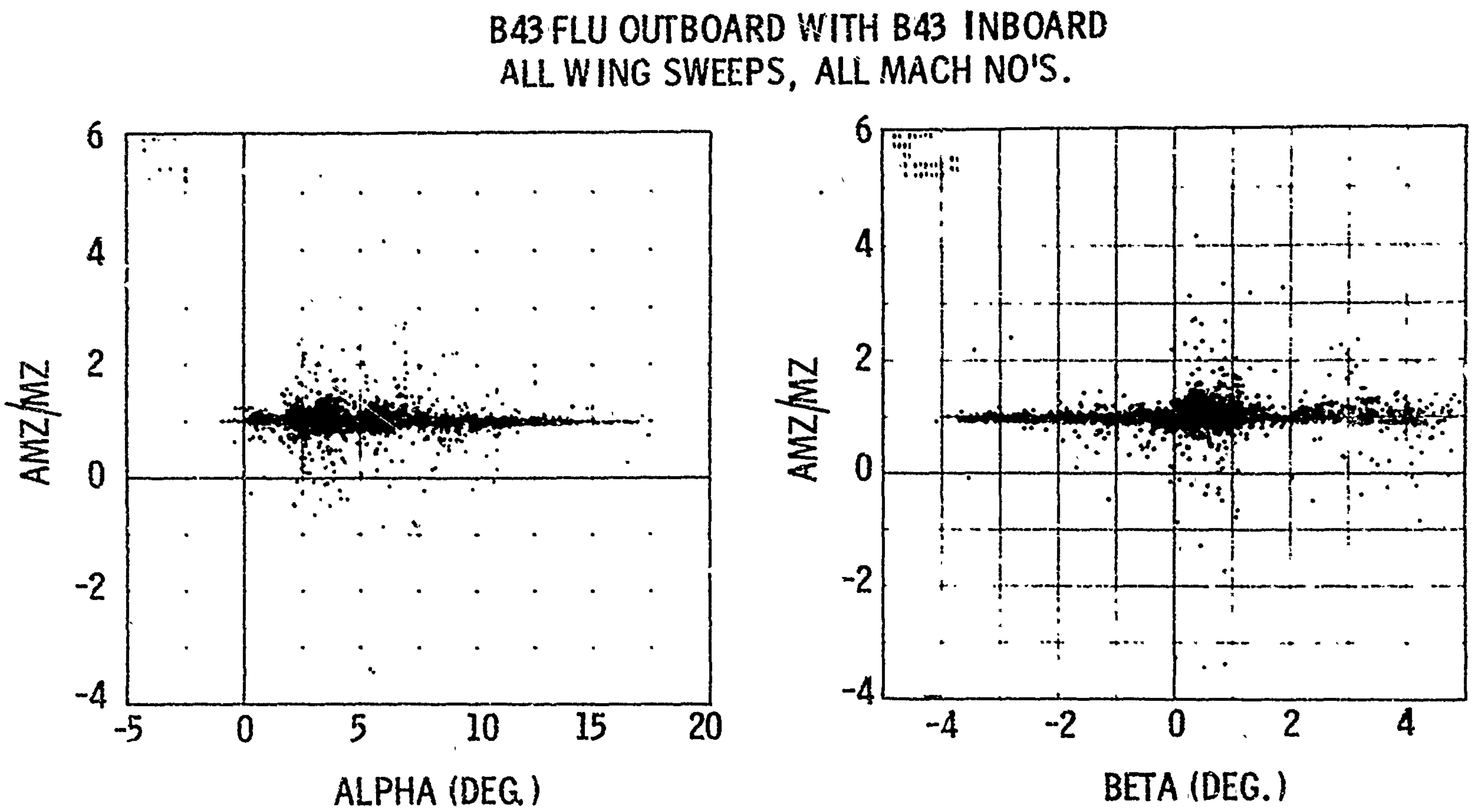


FIGURE 9: RATIO OF AERODYNAMIC YAW MOMENT TO TOTAL YAW MOMENT VS. ALPHA AND BETA

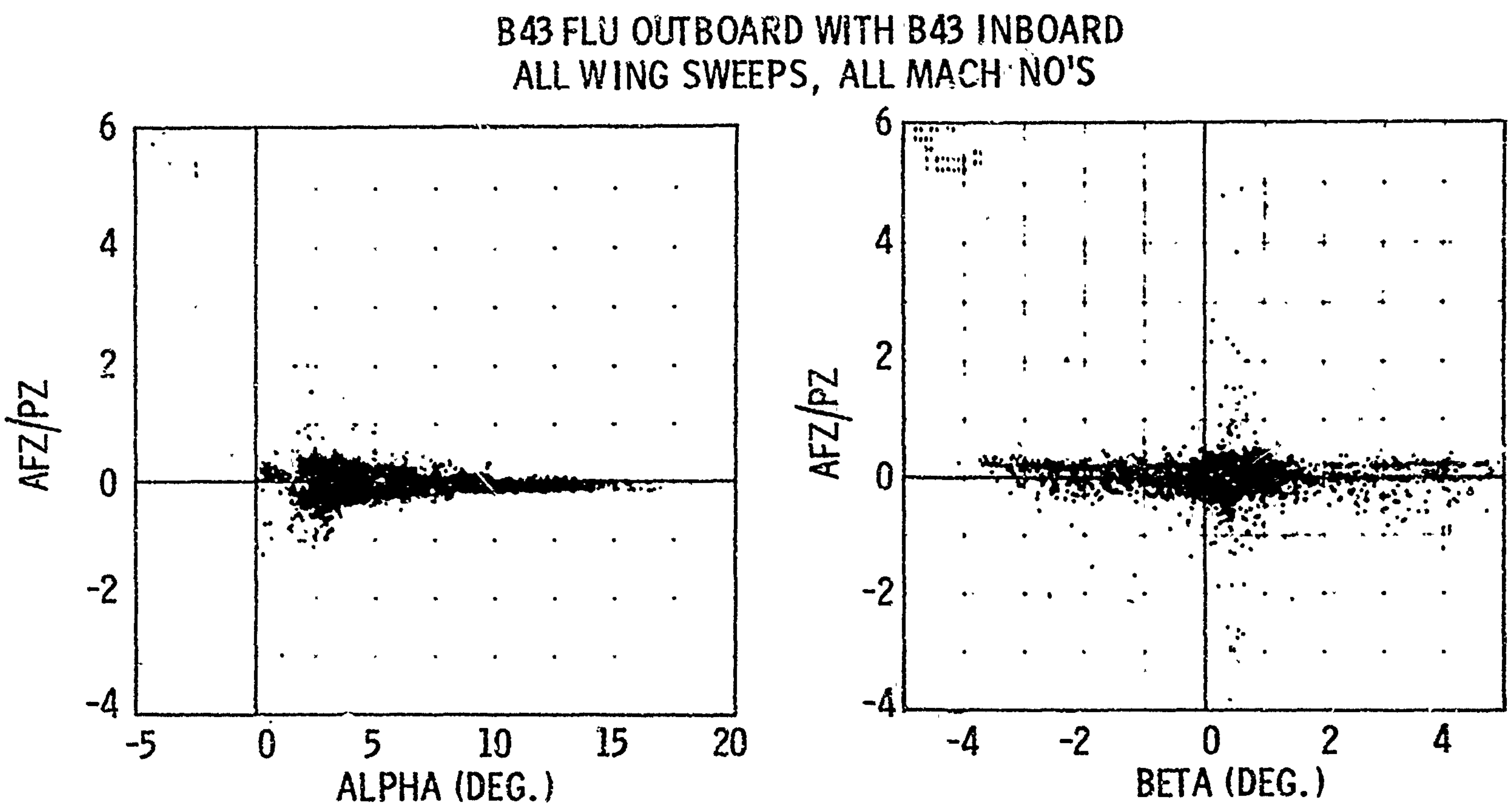


FIGURE 10: RATIO OF AERODYNAMIC NORMAL FORCE TO TOTAL NORMAL FORCE VS. ALPHA AND BETA

B43 FLU OUTBOARD WITH B43 INBOARD
ALL WING SWEEPS, ALL MACH NO'S.

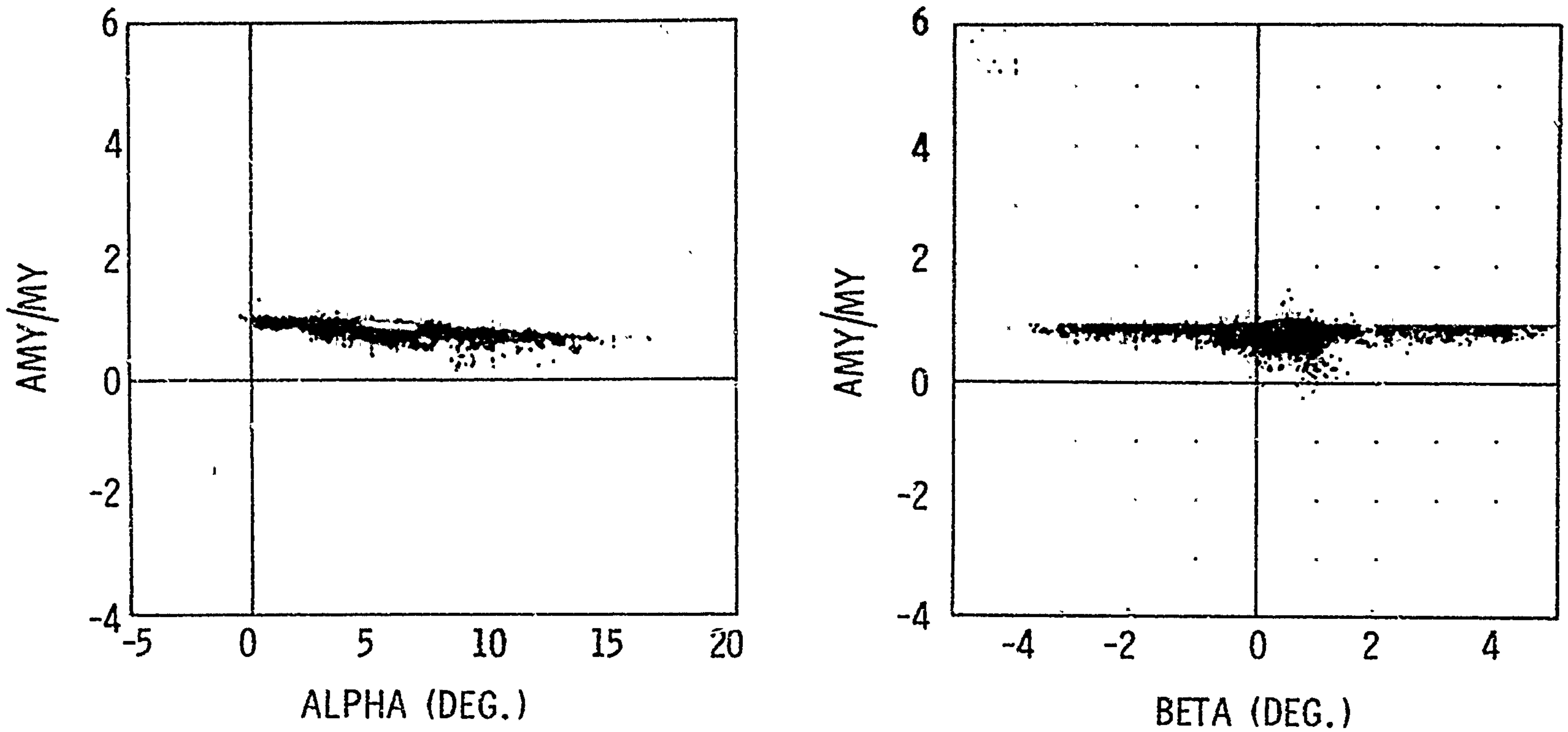


FIGURE 11: RATIO OF AERODYNAMIC PITCH MOMENT TO TOTAL PITCH MOMENT VS. ALPHA AND BETA

Comparison of FLU Aerodynamic Coefficients with Wind Tunnel Data

Figures 12 through 16 present aerodynamic coefficients derived from B43 FLU flights on the F-111A aircraft. The figures represent data for a limited range of wing sweep angles and a limited range of Mach numbers. Superimposed curves represent wind tunnel measurements of aerodynamic coefficients for a B43 bomb model mounted on an F-111A airplane model (1/20 scale). These figures indicate that the trends seen in the FLU data agree reasonably well with wind tunnel test results wh gives credence to both methods of testing. Most of the B43 FLU co cient data show a minimal amount of scatter which is also encouraging.

The rolling moment coefficient (CMX) in Figure 13 shows the best overall correlation. Slight differences in magnitude do not fit any detectable pattern.

Results in the pitch plane (CZ and CMY) show poor correlation. This is explained by the fact that most of the pitch plane loading was caused by inertia effects. Airloads were small compared to calibration levels required to measure total pitch plane loads. This leads to the conclusion that the suspended mass on any future FLU designs should be of minimum weight to alleviate this problem.

The yaw plane loading experienced by the B43 FLU was primarily due to aerodynamic effects. Yaw plane aerodynamic coefficients (CY and CMZ) correlate fairly well with wind tunnel results. Data slopes correlate extremely well. Magnitudes do vary (sometimes significantly), but no consistent transformation to improve the correlation was found.

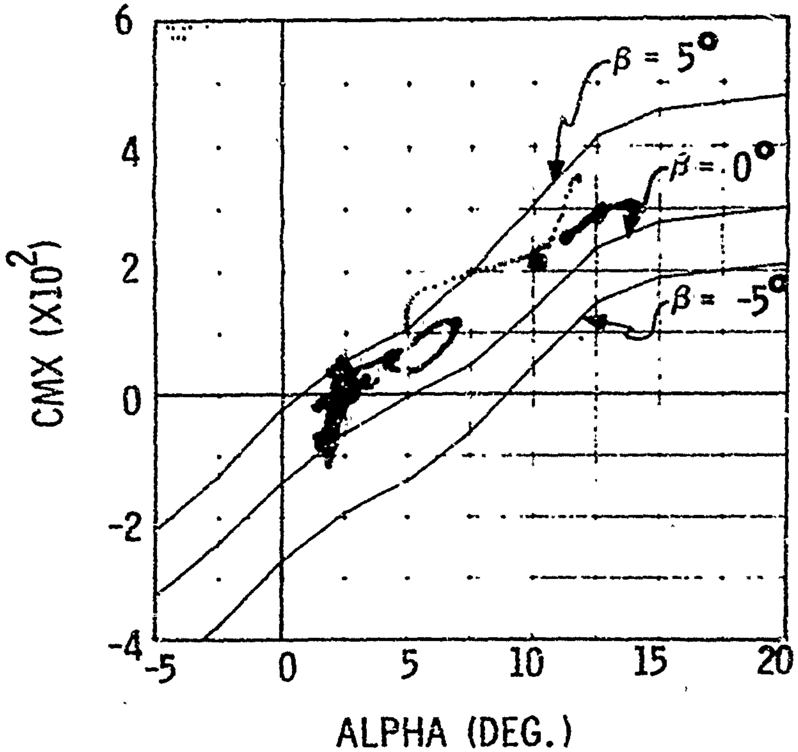
Unless future data study indicates reliable trends in FLU results which were not evident in wind tunnel results, we should continue using wind tunnel data with confidence.

Comparison of Aerodynamic Coefficients Derived from Total Force Balance with those from Nose and Fin Instrumentation

Figures 17 through 26 present comparisons of B43 FLU aerodynamic coefficients derived from (1) load cell instrumentation (shown at left for each group of plots) and from (2) the nose pressure transducers and fin balance instrumentation (shown at right for each group of plots). By combining integrated nose pressures with forces measured by the fin balance, we obtain a measure of how much of the distributed aerodynamic effects were measured.

Figures 17 and 18 show that the aerodynamic rolling moment measured by the roll moment transducer compares favorably with that derived from the fin instrumentation. Complementary results from the two instrumentation systems is encouraging.

B43 FLU OUTBOARD WITH B43 INBOARD
72.5 DEG. WING SWEEP, 1.35-1.45 MACH



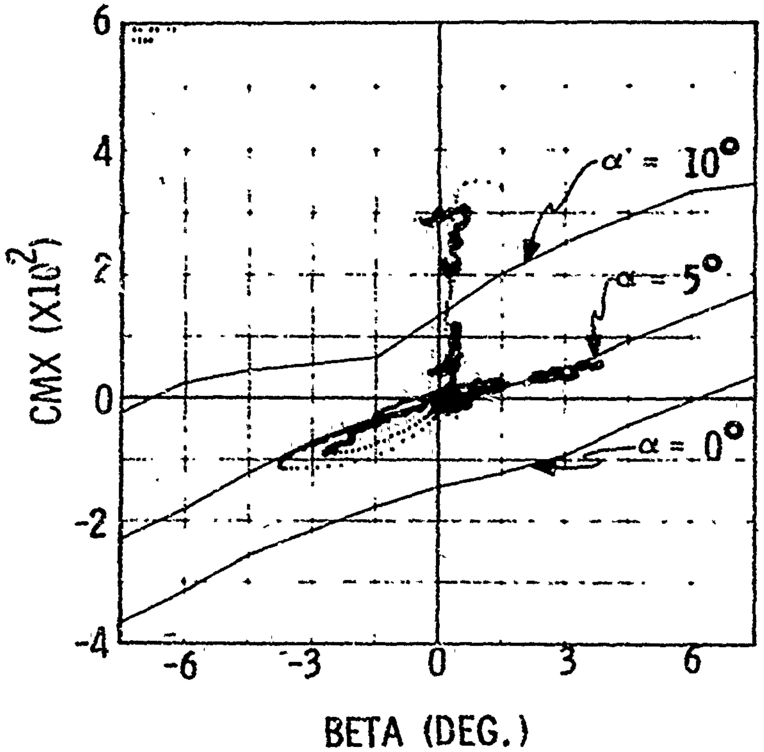


FIGURE 12: COMPARISON OF AERODYNAMIC ROLL MOMENT COEFFICIENTS FROM B43 FLU AND WIND TUNNEL TESTS

B43 FLU OUTBOARD WITH B43 INBOARD
72.5 DEG. WING SWEEP, 1.35-1.45 MACH

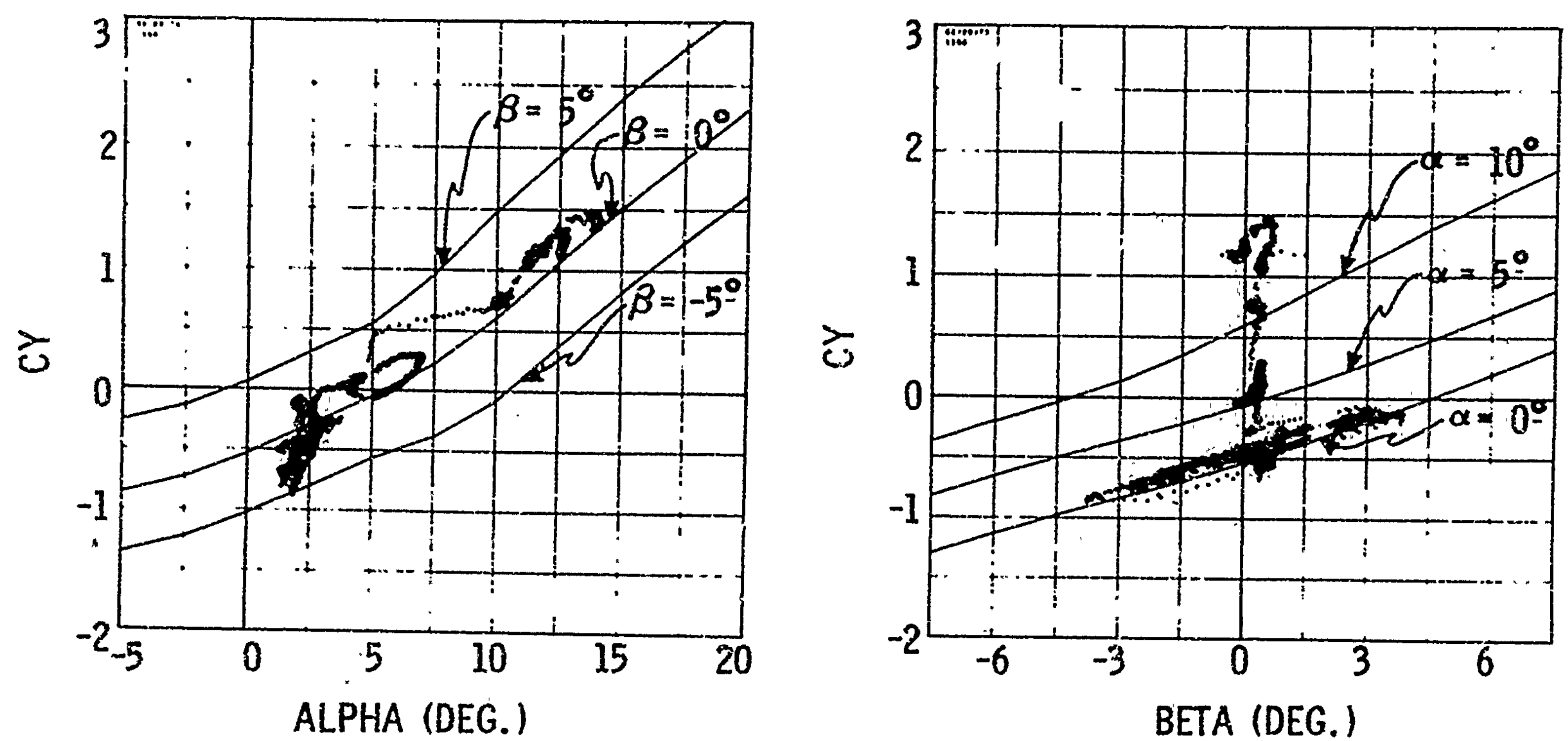


FIGURE 13: COMPARISON OF AERODYNAMIC SIDE FORCE COEFFICIENTS FROM B43 FLU AND WIND TUNNEL TESTS

B43 FLU OUTBOARD WITH B43 INBOARD
72.5 DEG. WING SWEEP, 1.35-1.45 MACH

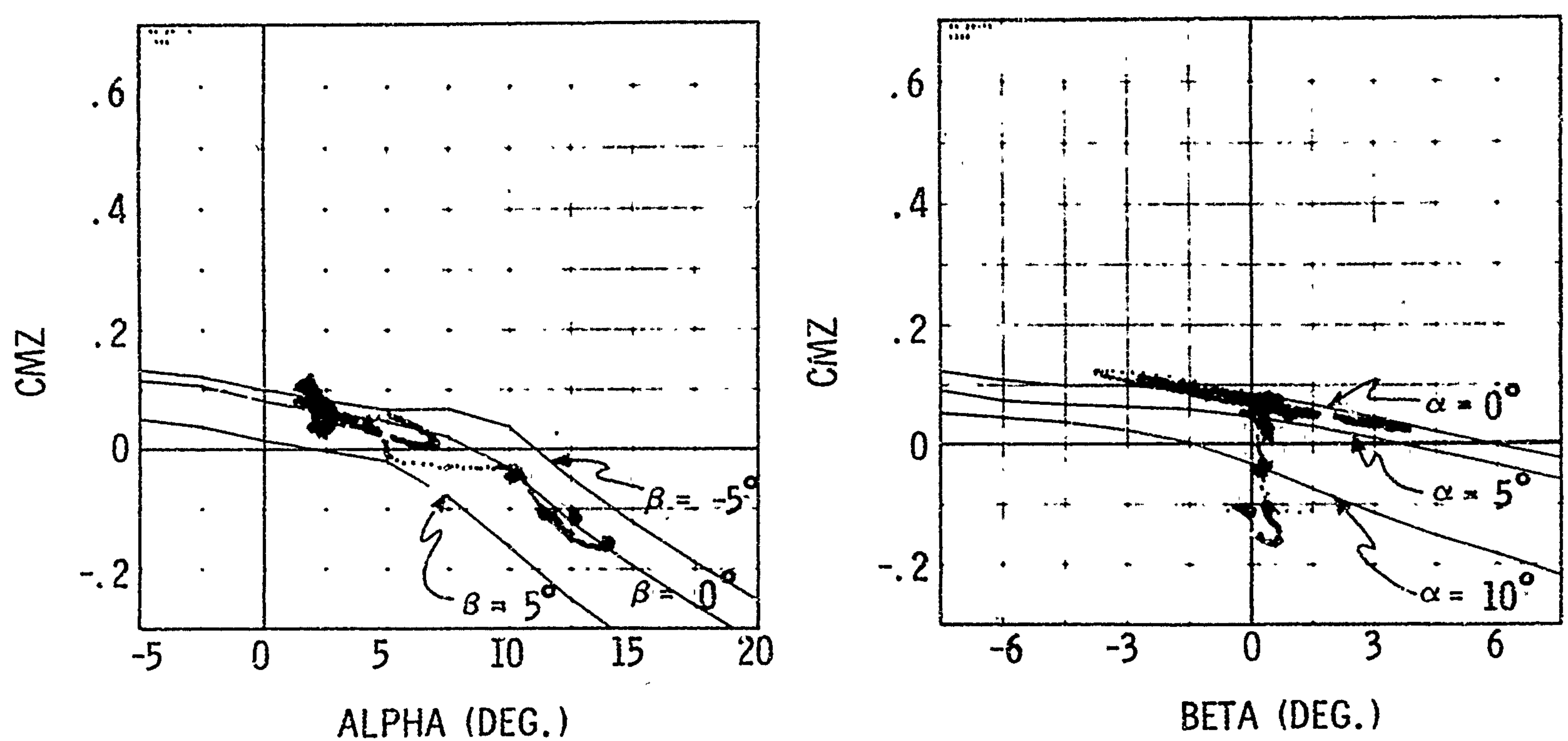


FIGURE 14: COMPARISON OF AERODYNAMIC YAW MOMENT COEFFICIENTS FROM B43 FLU AND WIND TUNNEL TESTS

B43 FLU OUTBOARD WITH B43 INBOARD
72.5 DEG WING SWEEP, 1.35-1.45 MACH

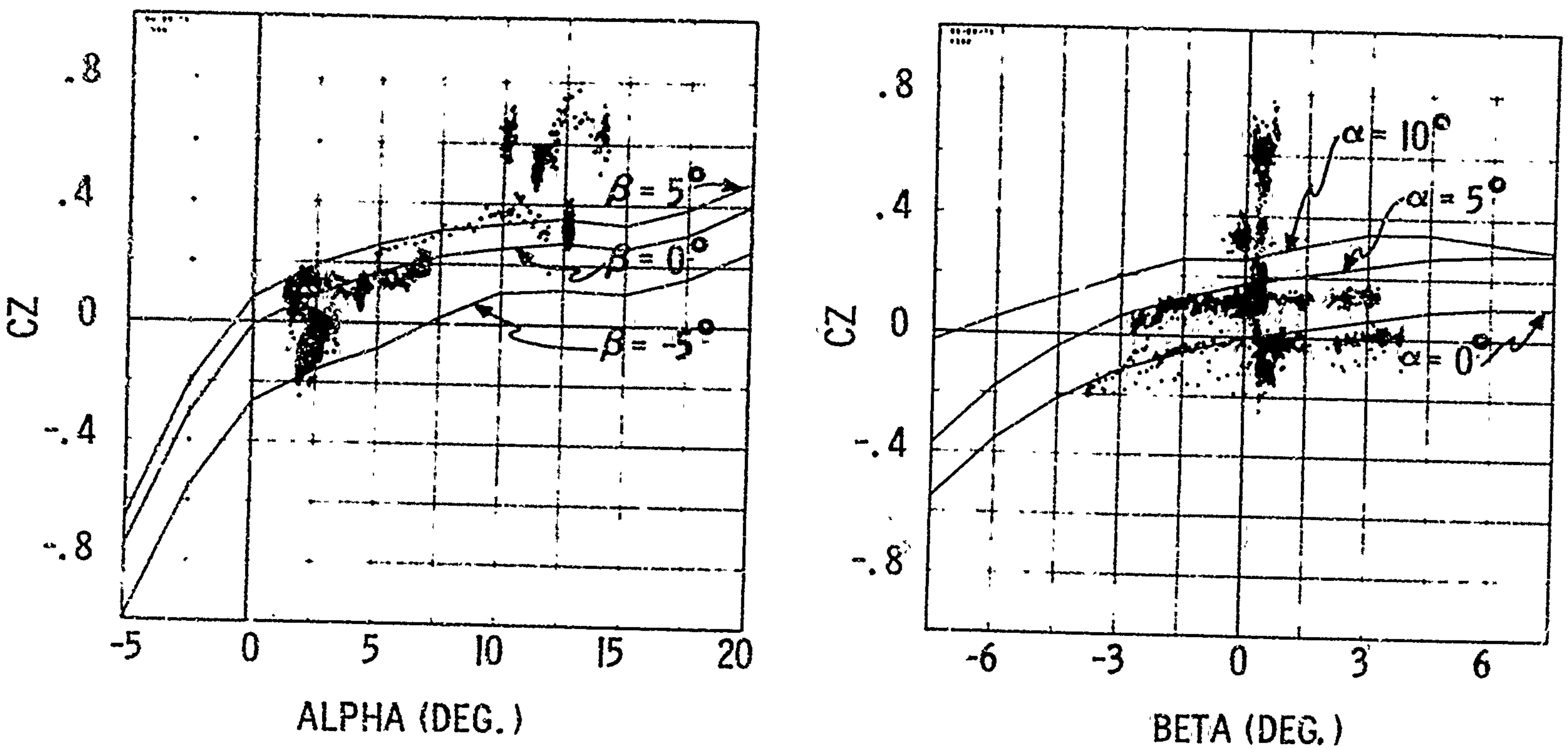


FIGURE 15: COMPARISON OF AERODYNAMIC NORMAL FORCE COEFFICIENTS FROM B43 FLU AND WIND TUNNEL TESTS

B43 FLU OUTBOARD WITH B43 INBOARD
72.5 DEG. WING SWEEP, 1.35-1.45 MACH

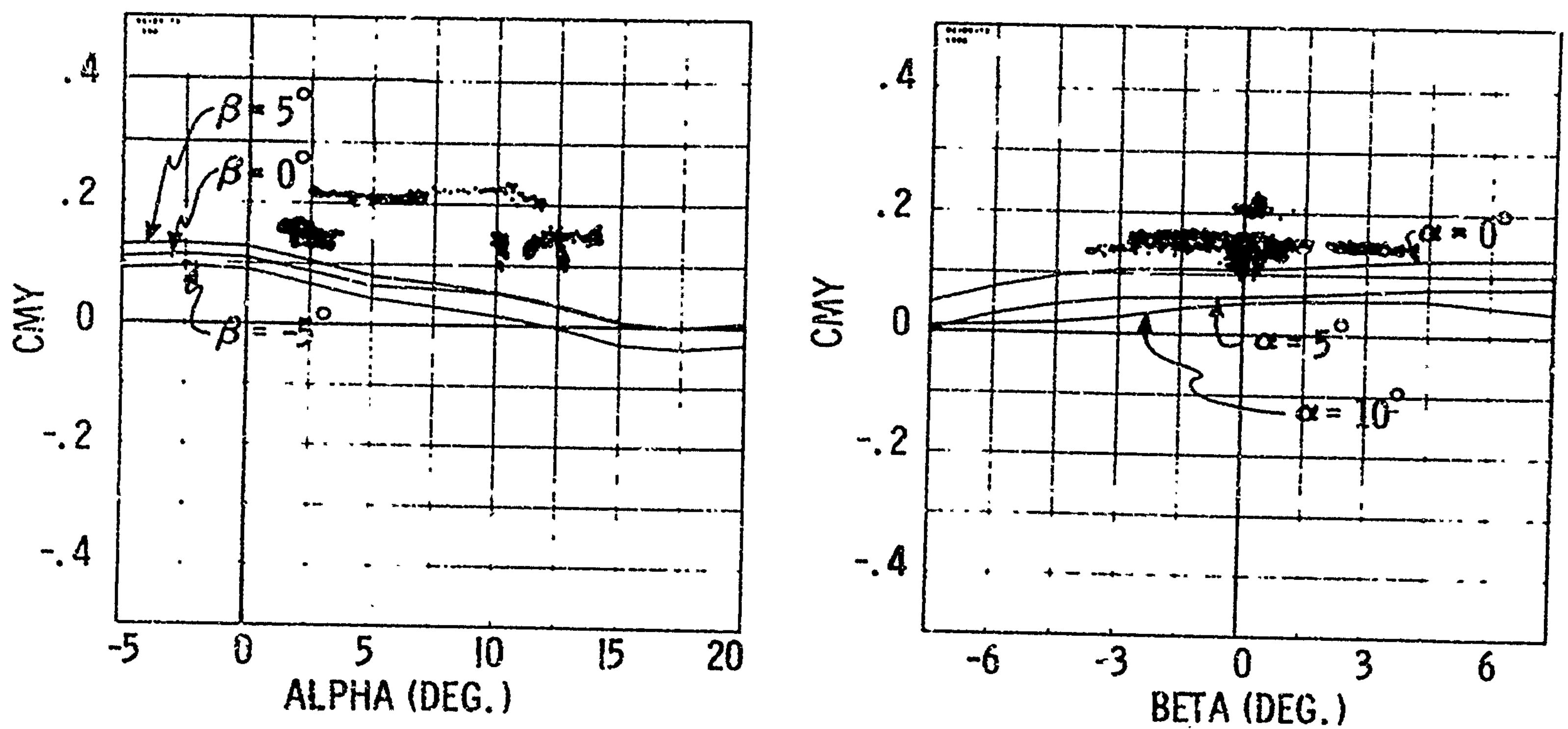


FIGURE 16: COMPARISON OF AERODYNAMIC PITCH MOMENT COEFFICIENTS FROM B43 FLU AND WIND TUNNEL TESTS.

B43 FLU INBOARD WITH B43 OUTBOARD
43 DEG WING SWEEP, 0.9 MACH

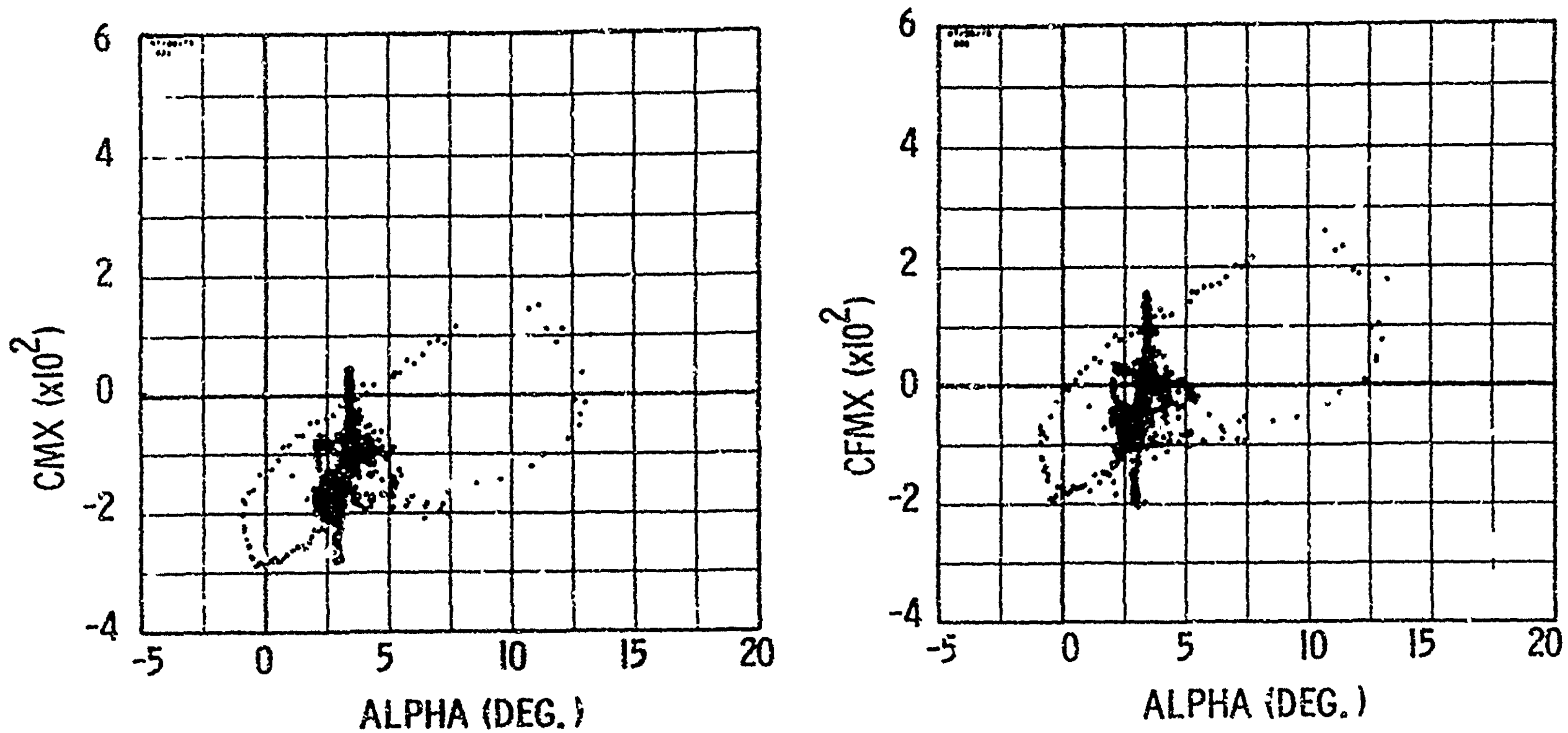


FIGURE 17: AERODYNAMIC ROLL MOMENT COEFFICIENT VS ALPHA FROM MAIN FORCE BALANCE (LEFT) AND FIN FORCE BALANCE (RIGHT)

B43 FLU INBOARD WITH B43 OUTBOARD
43 DEG WING SWEEP, 0.9 MACH

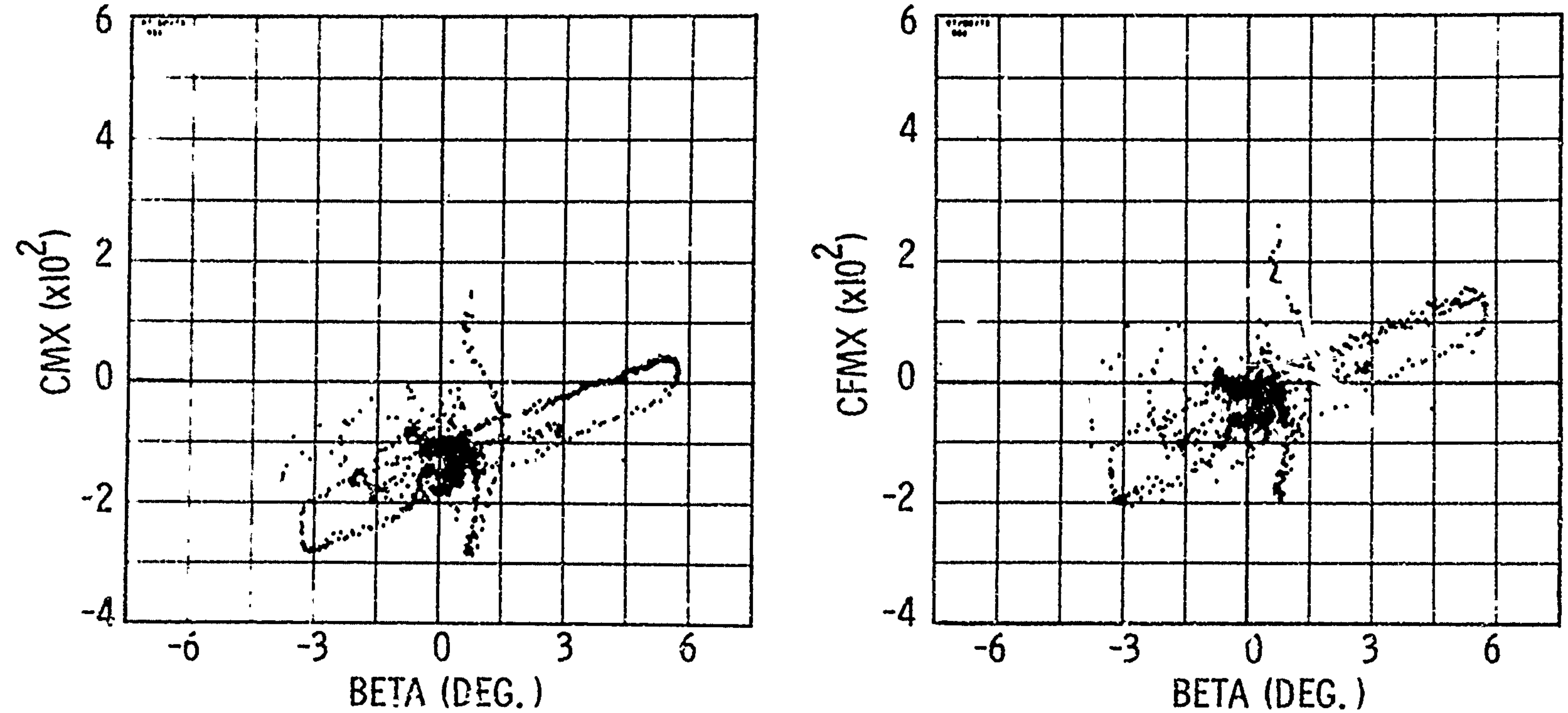


FIGURE 18: AERODYNAMIC ROLL MOMENT COEFFICIENT VS BETA FROM MAIN FORCE BALANCE (LEFT) AND FIN FORCE BALANCE (RIGHT)

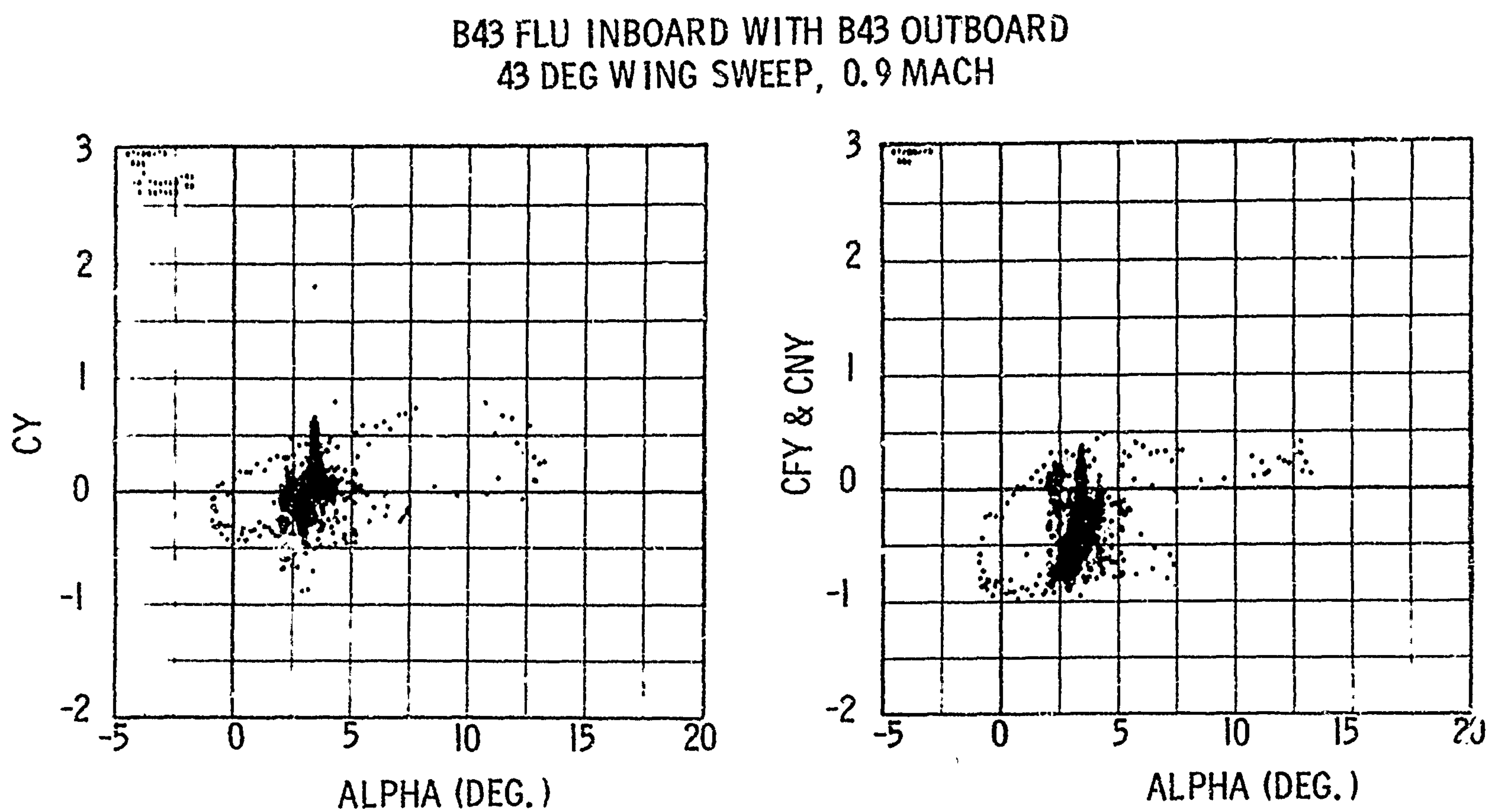


FIGURE 19: AERODYNAMIC SIDE FORCE COEFFICIENT VS ALPHA FROM MAIN FORCE BALANCE (LEFT) AND FROM NOSE PLUS FIN INSTRUMENTATION (RIGHT)

B43 FLU INBOARD WITH B43 OUTBOARD
43 DEG WING SWEEP, 0.9 MACH

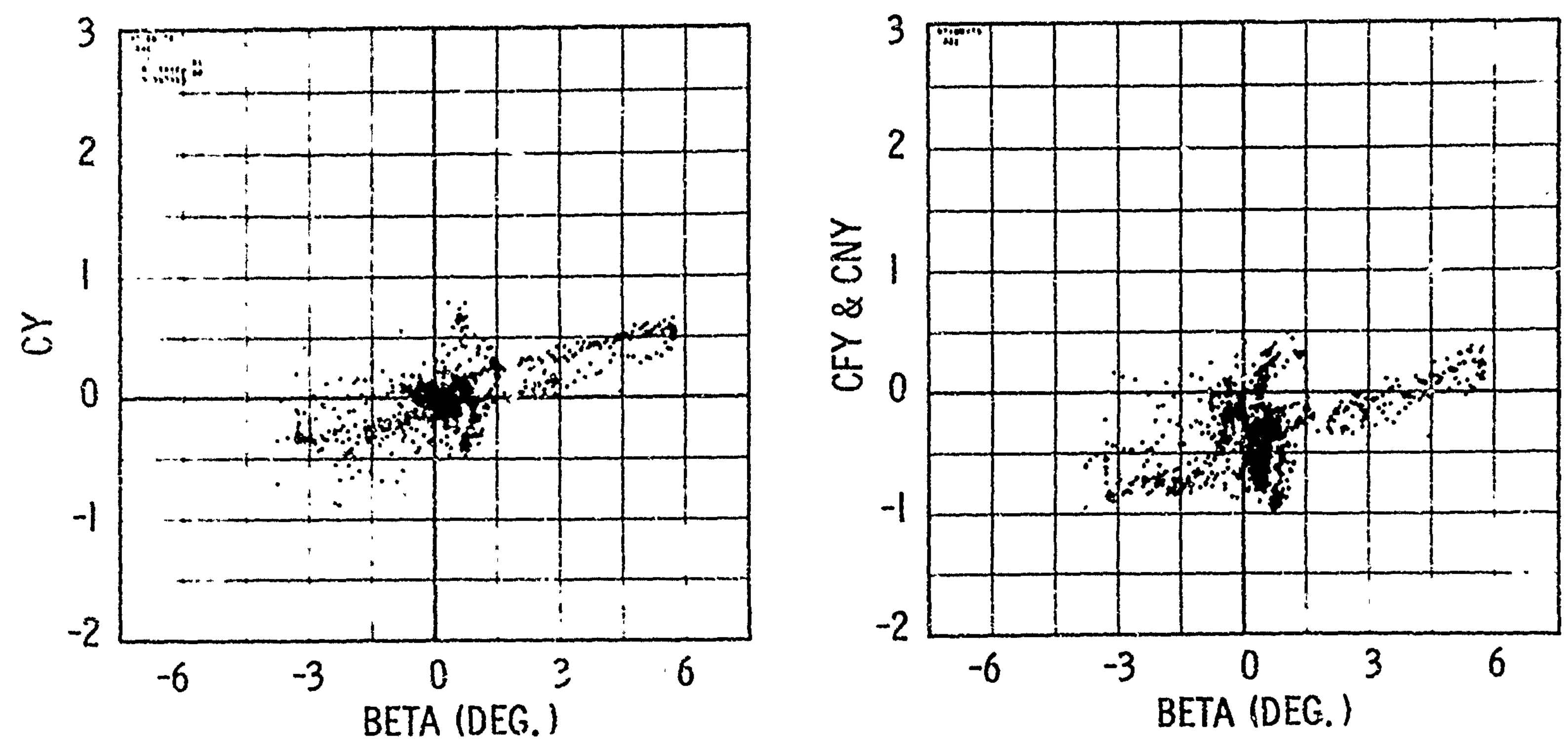


FIGURE 20: AERODYNAMIC SIDE FORCE COEFFICIENT VS BETA FROM MAIN FORCE BALANCE (LEFT) AND FROM NOSE PLUS FIN INSTRUMENTATION (RIGHT)

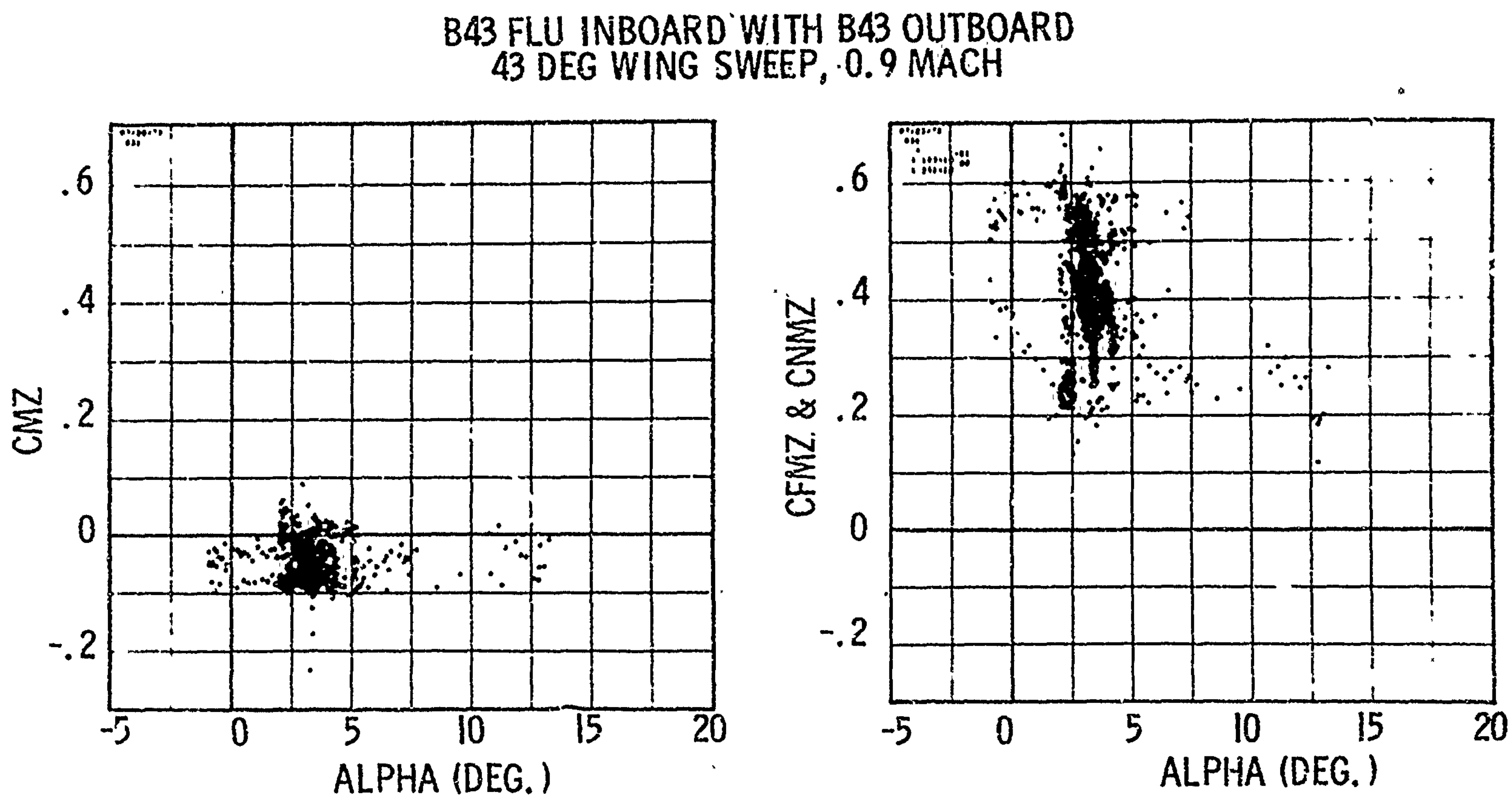


FIGURE 21: AERODYNAMIC YAW MOMENT COEFFICIENT VS ALPHA FROM MAIN FORCE BALANCE (LEFT) AND FROM NOSE PLUS FIN INSTRUMENTATION (RIGHT)

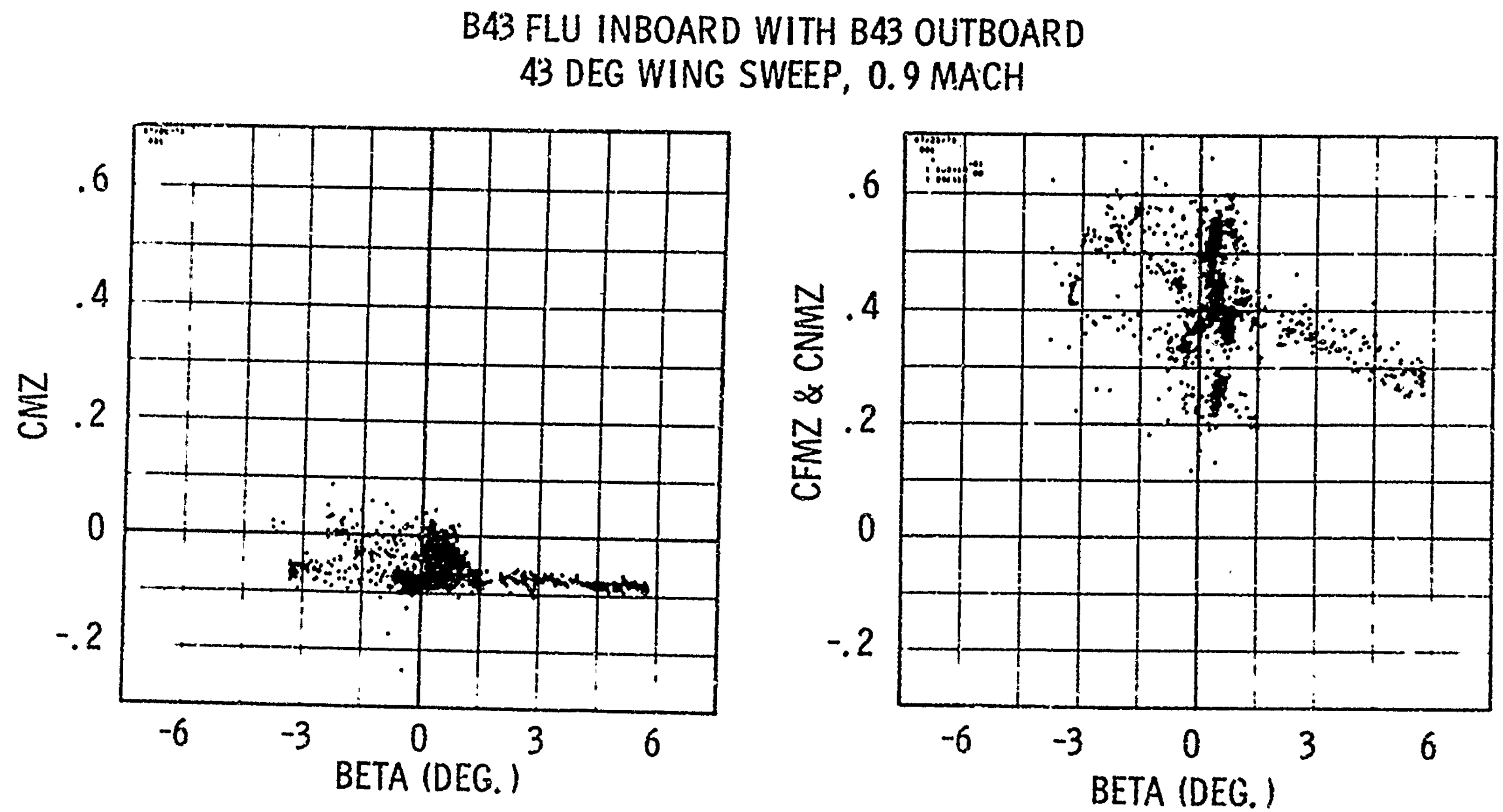


FIGURE 22: AERODYNAMIC YAW MOMENT COEFFICIENT VS BETA FROM MAIN FORCE BALANCE (LEFT) AND FROM NOSE PLUS FIN INSTRUMENTATION (RIGHT)

B43 FLU INBOARD WITH B43 OUTBOARD
43 DEG WING SWEEP, 0.9 MACH

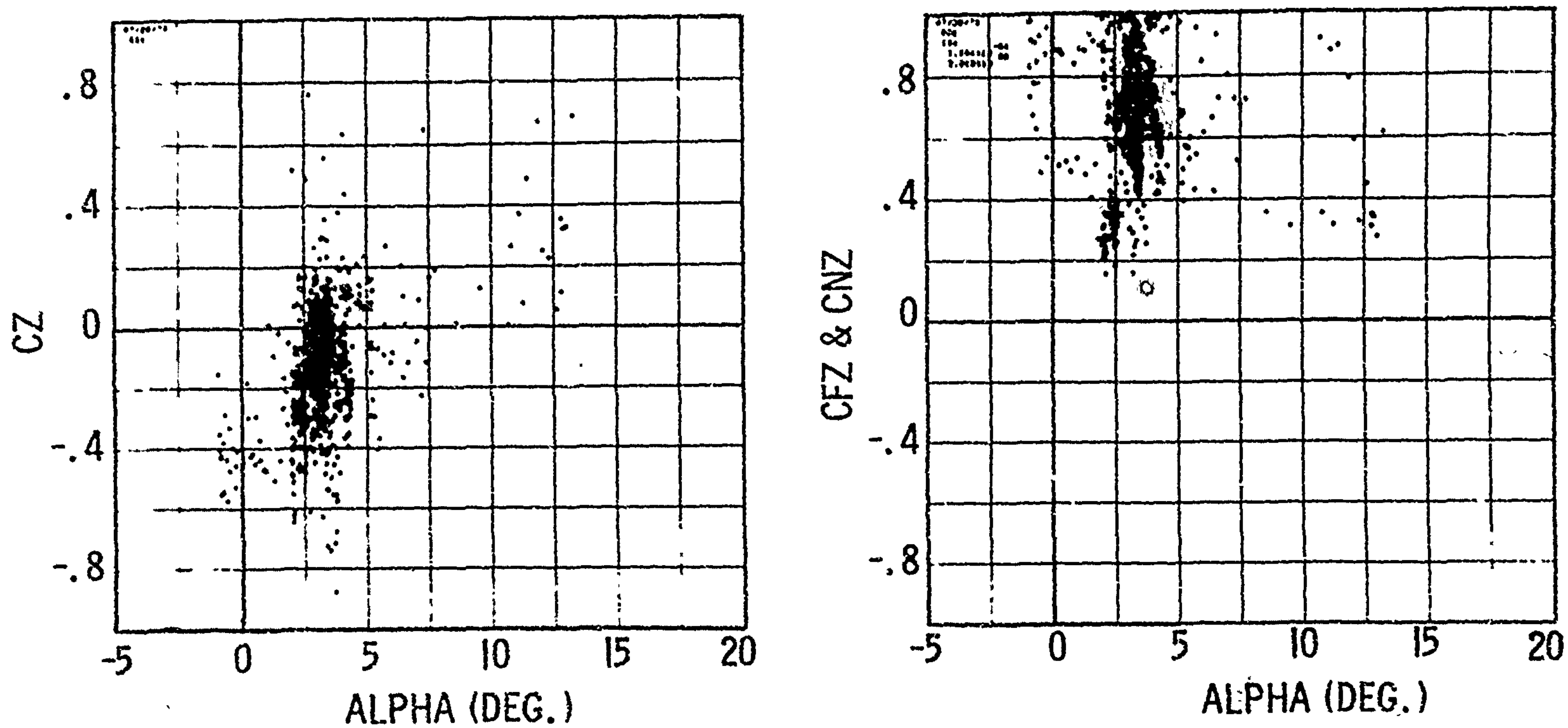


FIGURE 23: AERODYNAMIC NORMAL FORCE COEFFICIENT VS ALPHA FROM MAIN FORCE BALANCE (LEFT) AND FROM NOSE PLUS FIN INSTRUMENTATION (RIGHT)

B43 FLU INBOARD WITH B43 OUTBOARD
43 DEG WING SWEEP, 0.9 MACH

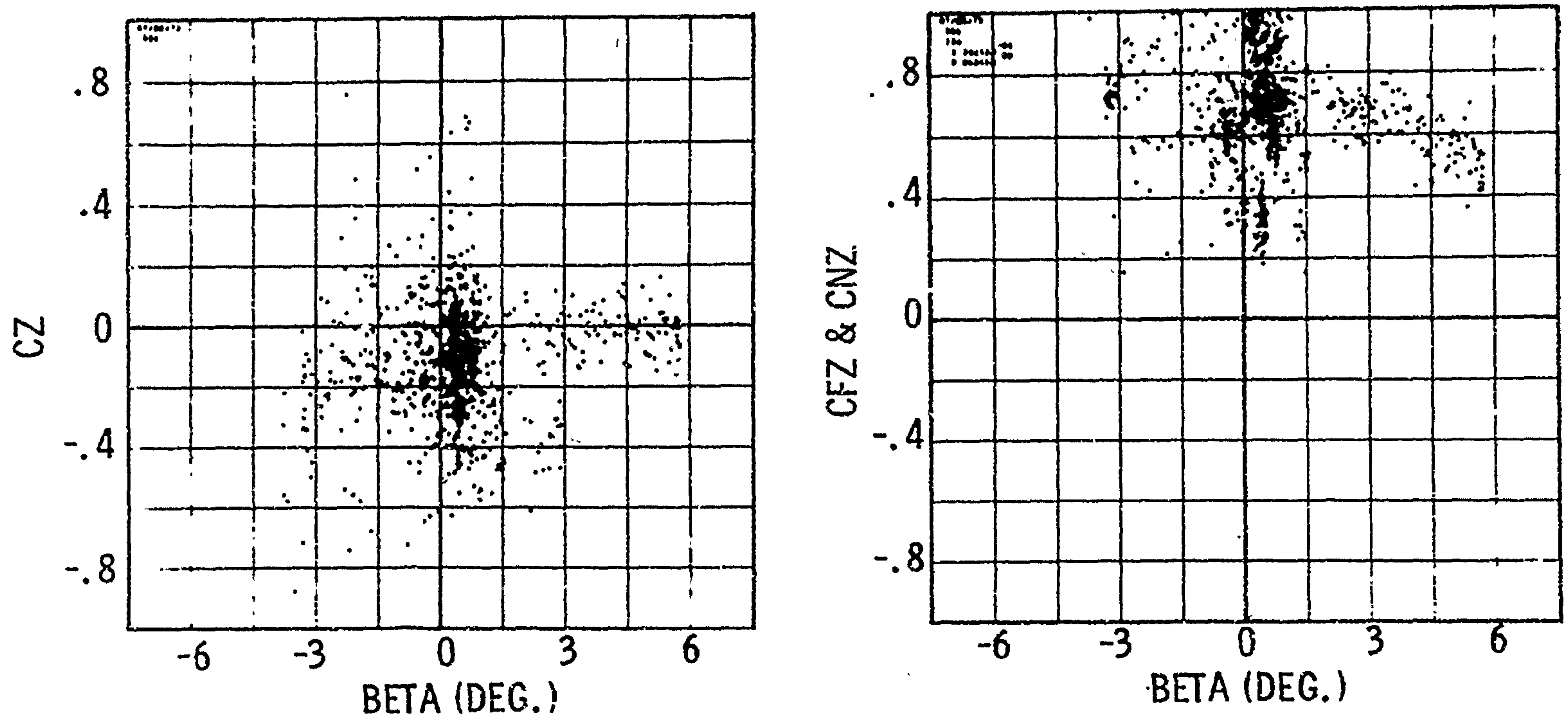


FIGURE 24. AERODYNAMIC NORMAL FORCE COEFFICIENT VS BETA FROM MAIN FORCE BALANCE (LEFT) AND FROM NOSE PLUS FIN INSTRUMENTATION (RIGHT)

B43 FLU INBOARD WITH B43 OUTBOARD
43 DEG WING SWEEP, 0.9 MACH

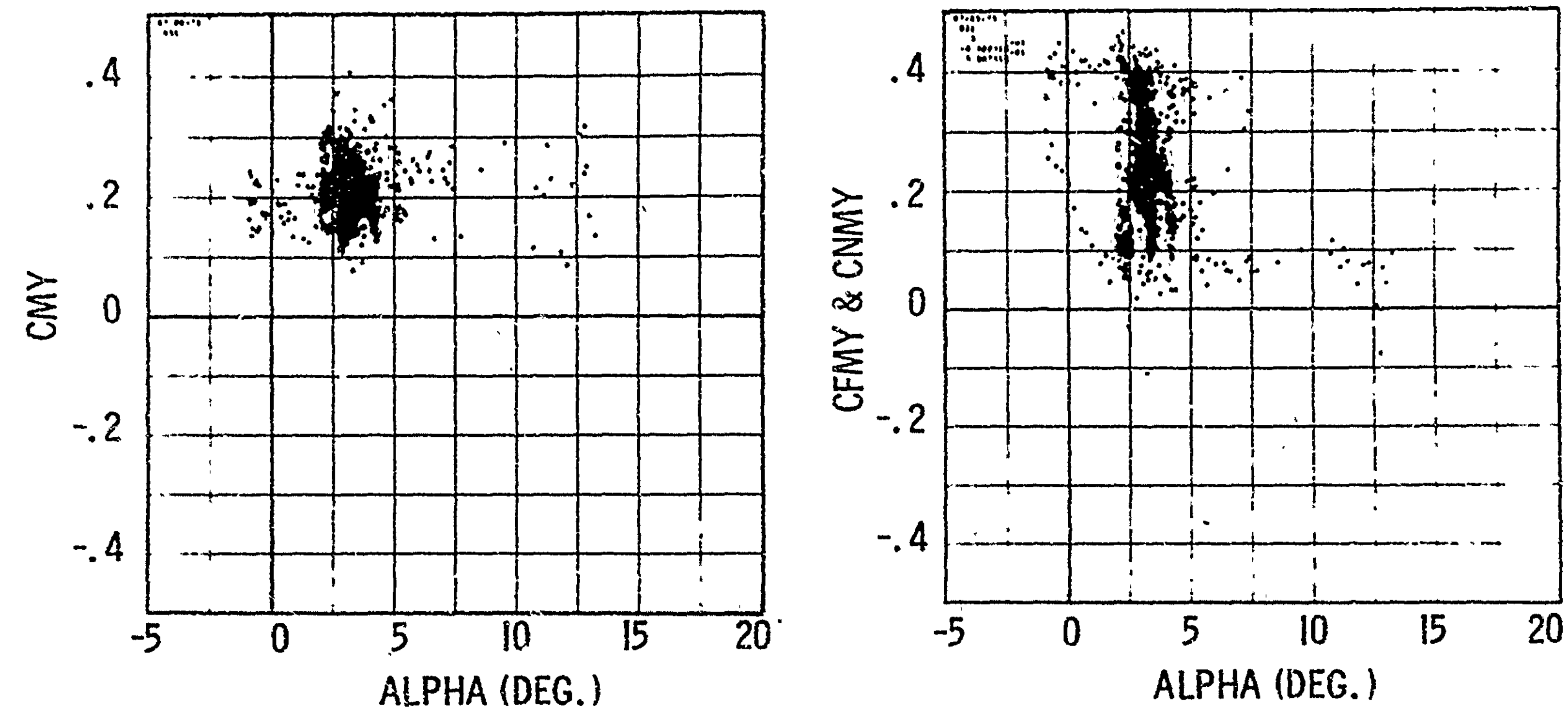
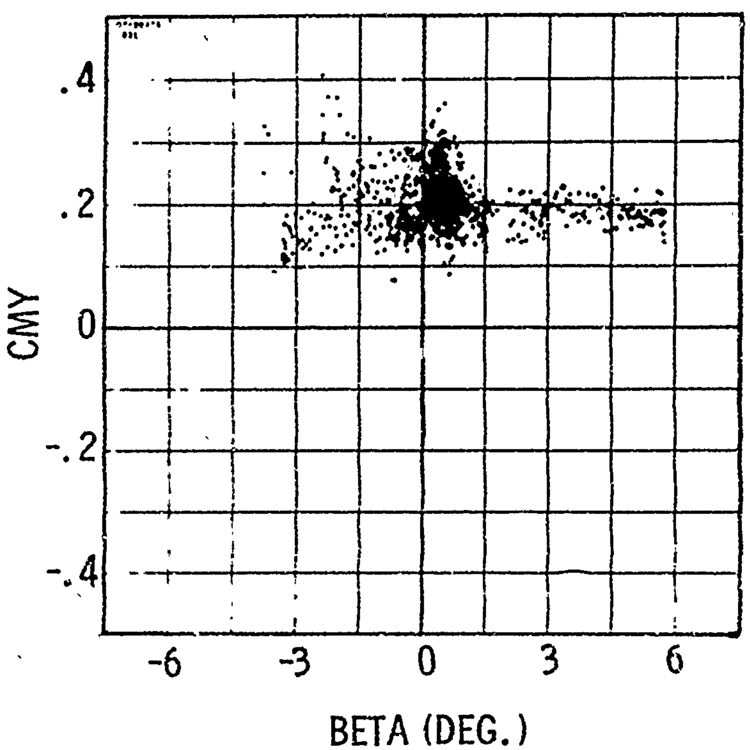


FIGURE 25: AERODYNAMIC PITCH MOMENT COEFFICIENT VS ALPHA FROM MAIN FORCE BALANCE (LEFT) AND FROM NOSE PLUS FIN INSTRUMENTATION (RIGHT)

B43 FLU INBOARD WITH B43 OUTBOARD
43 DEG WING SWEEP, 0.9 MACH



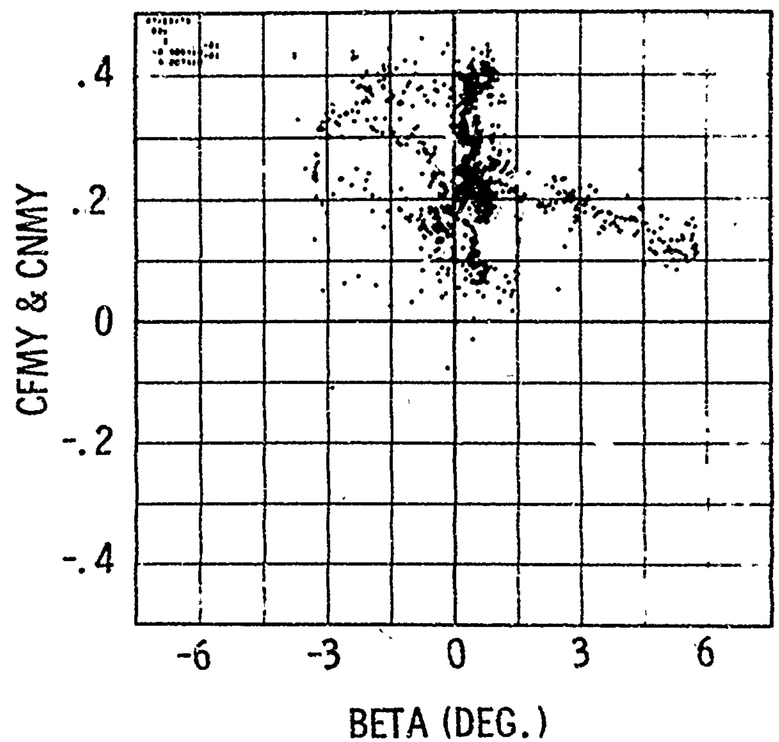


FIGURE 26: AERODYNAMIC PITCH MOMENT COEFFICIENT VS BETA FROM MAIN FORCE BALANCE (LEFT) AND FROM NOSE PLUS FIN INSTRUMENTATION (RIGHT)

Figures 19 through 22 indicate that lateral aerodynamic forces measured by load cells and by nose and fin instruments were similar but the yawing moment differs. Other plots (not shown) indicate that nose force acts outboard, combined fin forces act inboard--both contributing directly to yawing moment whereas the difference defines the side force. These facts indicate that additional airloads may act on the remainder of the FLU, creating moments that could produce better agreement between the data shown in Figures 21 and 22.

Figures 23 through 26 show similar comparisons for normal force and pitching moment. However, in this case, normal force compares poorly while pitching moment compares favorably. Other plots (not shown) indicate a small nose force acting upward, a large fin force acting upward. Balancing forces would have to act downward without changing pitching moment to produce better correlation.

GENERAL DISCUSSION OF AIRLOAD DISTRIBUTIONS

The B43 FLU flight tests provided a wealth of nose and tailcan pressure data. Numerical integrations of these pressures have been performed and results compared to earlier prediction techniques. Such comparisons indicate that the old techniques yielded un-conservative nose forces. Although comparison of tailcan airloads is not complete, it appears that earlier techniques produced over-conservative tailcan airloads. The pressure distributions are not available in a suitable form to include in this paper. The details of comparisons with old prediction techniques has been withheld because conclusions are valid only within the range of flight conditions experienced to date. Additional study is planned.

The fin force data collected is less extensive, as some data were lost due to strain gage and/or telemetry problems. Where fin force data were collected on all four fins, limited comparisons show that fin forces predicted by old techniques are un-conservative. Additional study is also planned in this area.

CONCLUSIONS

The basic FLU concept employed to obtain total aerodynamic coefficients on an external store appears to have been worthwhile. FLU results seem to support the validity of wind tunnel testing as a means of obtaining total aerodynamic force and moment coefficients. It is believed that further study of the FLU data will provide additional support of this conclusion.

The FLU allows determination of external store forces, moments, suspension reactions, fin forces, etc., versus time. This capability may prove quite useful in selecting optimum store release conditions or in establishing missile control surface deflection requirements necessary to minimize carriage loads or broaden safe separation envelopes.

The FLU concept of measuring aerodynamic load distributions on external stores provides a much needed capability. Wind tunnel scale models cannot be adequately instrumented to measure aerodynamic distributions. Although some difficulties were encountered with the B43 FLU instrumentation and data gathering system, the aerodynamic distribution data collected appears useful. Within the limits of the flight environments experienced by the B43 FLU, full scale pressure distribution data for the B43 nose surfaces and tail cone and some fin loading data have been obtained. Previous estimates of aerodynamic load distributions have been found to be un-conservative.

The B43 FLU results provide the experience to design better test units for future collection of captive store loading. A redesigned FLU would employ a minimum weight aerodynamic shell (suspended mass) and would possibly include additional gauges (for reliability considerations) on the fin force balance. An internal recording system might be an improvement over use of telemetry. The extensive instrumentation employed on the B43 FLU builds confidence in various methods of recording loads. This may lead to the design of simpler test units in the future to satisfy more limited data needs.

BIOGRAPHY

Mr. S. D. Meyer received his B.S. degree in Mechanical Engineering from the University of Toledo in 1957. After four years in the glass industry he returned to school and received his MSME from the University of Toledo in 1962. After teaching for one year in the Department of Mechanical Engineering, he joined Sandia Laboratories. His initial assignment at Sandia was in the area of environmental testing. The past six years have been spent working in engineering analysis. Areas of responsibility have included both loads and structural analyses. Mr. Meyer is a member of the ASME.

BIOGRAPHY

Mr. C. E. Sisson holds an AAS degree in Mechanical Technology from the State University of New York, Agricultural and Technical Institute at Alfred, New York. Since joining Sandia Laboratories in July 1958, Mr. Sisson has had extensive experience in structural load analysis of bombs for carriage and delivery environments. Current assignment is in heat transfer computer code development. However, because of previous experience in loads analysis, Mr. Sisson is participating in the evaluation of the B43 FLU test results. Mr. Sisson is a member of AIAA.

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EXTERNAL STORE LOADINGS IN
THE PROPOSED MIL-A-8591E
(U)
(Article UNCLASSIFIED)

by

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ABSTRACT. (U) In the proposed Military Specification revision MIL-A-8591E, Airborne Stores and Associated Suspension Equipment; General Design Criteria for, some changes have been advocated to improve the criteria for structural design loadings on external stores. The two major changes are in the airloads criteria and the lug and swaybrace reactions calculation method.

Previously, the airloads on an external store were specified by criteria that related angle of attack to aircraft performance, and were based on the most critical aircraft in the service inventory. In the revision these criteria have been generalized and are expressed in equation form. The numerical values of the criteria are calculated from specific geometric and performance parameters, which can represent either a specific aircraft, a group or class of aircraft, or a conservative design, as desired by the procuring agency.

A method of calculating lug and swaybrace reactions to applied loads, included in the specification as an Appendix, has also been modified. Assumptions that were necessary for treatment of the statically indeterminate yawing moment reaction were modified based on the results of laboratory testing. The updated method utilizes a load distribution factor which is a function of the suspension system and for which values have been empirically determined.

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LIST OF SYMBOLS

Symbol	Definition
C_L	Lift force coefficient of aircraft wing (nondim.)
C_{L_α}	Slope of lift curve (1/deg.)
C_Y	Side force coefficient of aircraft (nondim.)
C_{Y_β}	Slope of side force curve (1/deg.)
L	Lift force (lbs.)
n_Y	Side inertia load factor (nondim.)
n_Z	Vertical inertia load factor (nondim.)
r	Aircraft roll rate (deg./sec.)
q	Dynamic pressure, $\frac{1}{2} \rho V^2$ (lb./ft.^{2})
R	Lateral distance from aircraft centerline to store C.G. (ft.)
S	Reference aircraft wing area (ft.^{2})
V	Velocity (ft./sec.)
V_R	Velocity due to rolling (ft./sec.)
W_a	Aircraft gross weight
Y	Side force (lbs.)
α	Angle of attack (deg.)
α_o	Angle of zero lift (deg.)
α_M	Maximum angle of attack (deg.)
α_R	Angle of attack due to roll (deg.)
β	Angle of sideslip (deg.)
β_M	Maximum angle of sideslip (deg.)
ρ	Air density (slugs/ft.^{3})

INTRODUCTION

Since before its D revision was issued in 1968, the widely used Military Specification MIL-A-8591 has been the subject of some controversy over structural loading provisions. This controversy still continues, and an attempt is being made in the E revision to resolve the differences. It is true that many of the criticisms expressed to the Navy have been based on mis-application of the criteria in the specification. For instance, the nature of the loads on a store carried by a helicopter will be different than if the store were carried by a conventional aircraft. Recognizing this difference, the αq method of specifying angles of attack for airloads, as put forth in the specification, should not be expected to yield accurate angles for a helicopter. However, some of the comments have appeared to be justified. By the criteria in the D version, critical angle of attack values by which store airloads are obtained were more than four times as high for a given aircraft as by previous versions. For many patrol and attack aircraft which regularly carry external stores, the resulting angles of attack were physically unreasonable. At the same time, it was being recognized that the lug and swaybrace reactions calculation method in the Appendix did not always give sufficiently accurate results. Laboratory tests of actual store/rack configurations showed significantly different load distributions than predicted, and a paper at the first Aircraft/Store Compatibility Symposium in 1969 by two Air Force engineers was the first to propose a modification to improve the method. Therefore, when the go-ahead was given to develop a revision, these two areas were recognized as prime candidates for updating. The draft of the proposed MIL-A-8591E has been circulated through government and industry for comments in the past year. Some significant comments have been received, and the present status of the specification revision is that these comments are in the process of being resolved.

CAPTIVE FLIGHT AIRLOADS

BACKGROUND

The specification contains general design criteria, including structural design criteria, for the store or suspension equipment. These criteria are to ensure that the structural design will survive its service environment. They should, therefore, provide for design loads that are the most critical that might be encountered in service. A loading condition for an airborne external store can consist of inertia loads due to the maneuvering of the carriage aircraft and airloads on the body and aerodynamic surfaces of the store itself. In the proposed revision no changes have been made to

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the inertia load criteria contained in the specification. A modification is proposed, however, for the airloads criteria. This modification, it will be shown, is simply a generalization of the previous criteria.

The maximum airloads that a store may encounter at a given speed are a function of the store's angle of attack and its aerodynamic characteristics. In this general specification, airloads criteria are presented by means of specifying the range of angles of attack that the carriage aircraft is capable of as a function of dynamic pressure q. Obtaining store angles of attack from aircraft angles of attack is the responsibility of the designer. The αq method of specifying airloads criteria was originated 20 years ago for MIL-A-8591. At that time, a survey was made of the maximum αq capabilities of Navy fleet aircraft. Maximum αq was attained while performing a maximum n_z symmetrical pull-up at maximum speed. The survey showed a relatively close grouping of maximum αq capabilities. The aircraft that were included in the survey are shown in Figure(1). The value chosen to be the general criterion in MIL-A-8591 was 8000. As can be seen in Figure(1), the extreme values of a few extraordinary aircraft were disregarded in choosing this criterion.

As mentioned above, the maximum αq value occurs during a symmetrical pull-up maneuver. It can be shown that the αq values corresponding to the other critical aircraft maneuvers are related to this pull-up condition, and need not be derived separately. The negative symmetrical condition has been shown to be approximately -0.6 times the maximum; and the positive and negative rolling pull-out conditions have been derived as 0.8 and -0.4 times the maximum, respectively. The additional term in the rolling pull-out equations for αq is the incremental angle of attack due to the aircraft rolling velocity. The value of the term was based on the calculation of this angle for an assumed aircraft rolling velocity of 4 radians per second, at an altitude of 10,000 feet, and a store spanwise location on the wing of 15 feet.

The criterion of 8000 was not changed until the D revision of MIL-A-8591 was released in 1968. By the 1960's, the value of 8000 was no longer representative of the maximum for operational jet fighters. Higher wing loadings, along with higher operational speeds which dictate smaller values of C_{L_α}, are the two major factors which appear to have caused the trend of increasing αq capabilities. The value chosen for the D revision was 38,000, which represented the most severe αq value found among contemporary fighter aircraft. The capabilities of the Navy fighter and attack aircraft of the period are shown in Figure(2). All of the aircraft shown in Figure(2)are currently operational.

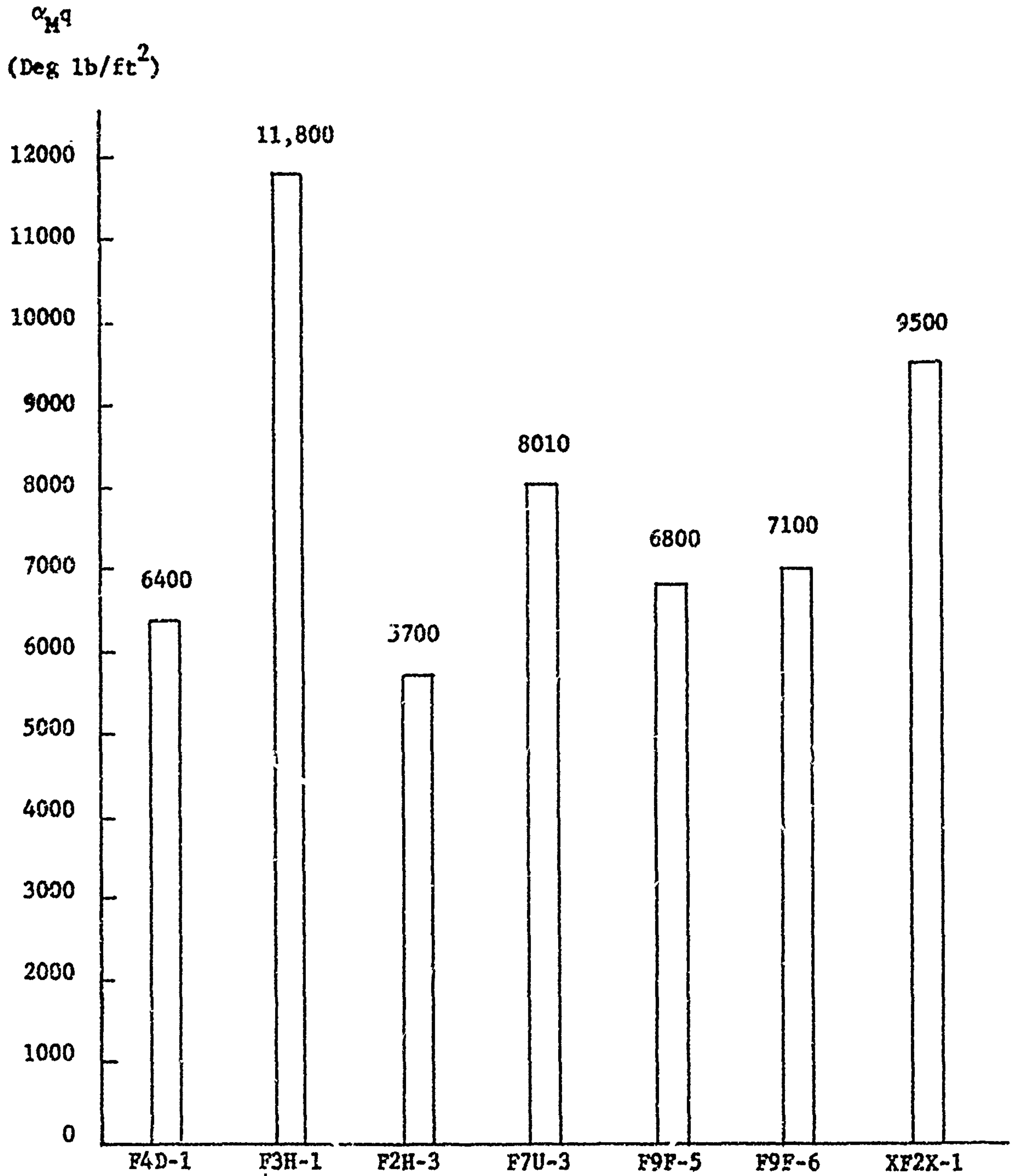


Figure 1. Maximum αq Values for 1953 Vintage Navy Fighter Aircraft

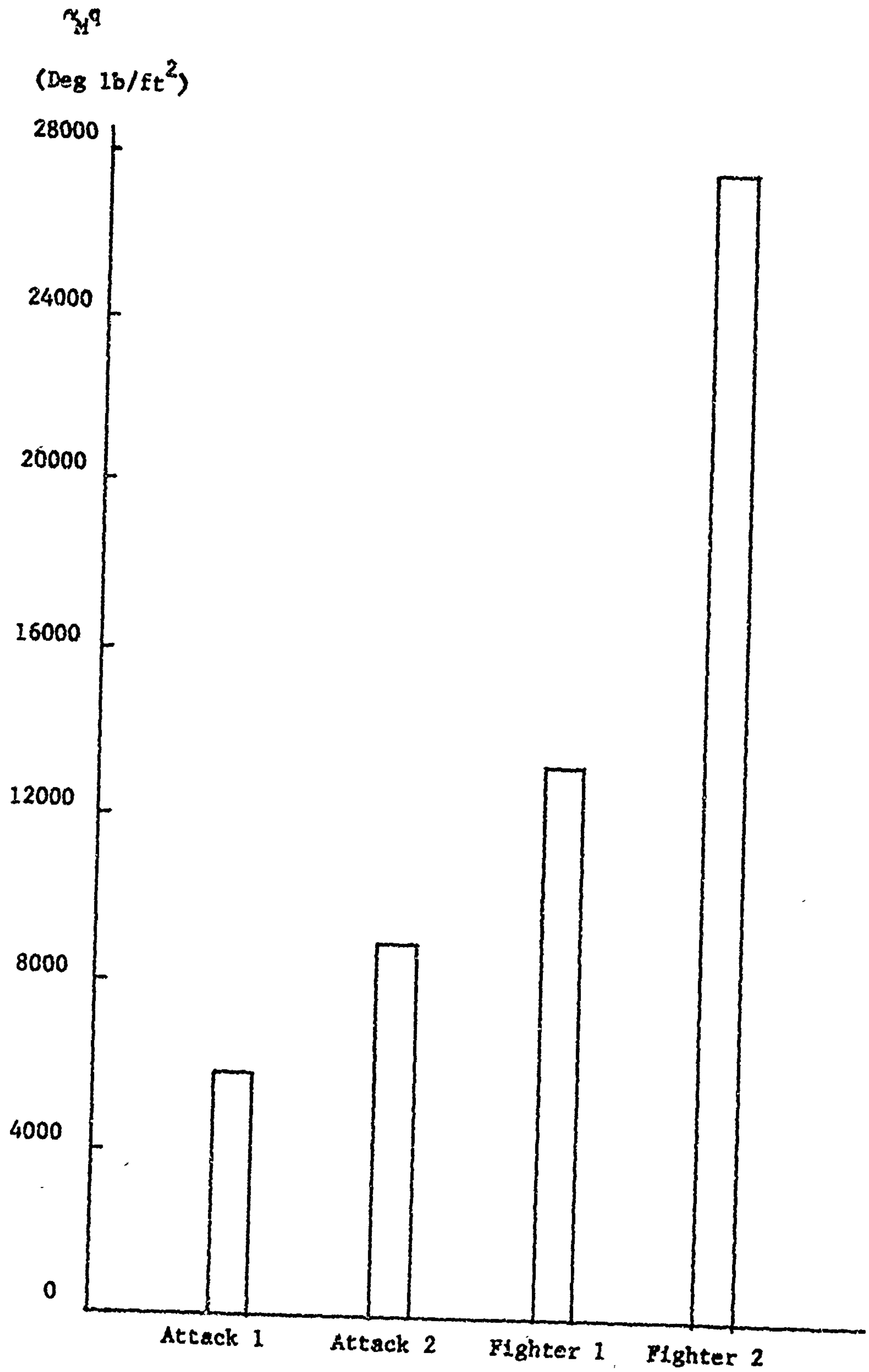


Figure 2. Maximum αq Values for Some Current Navy Fighter and Attack Aircraft

METHOD

An approximate maximum αq value for an aircraft can be calculated in a fairly straightforward manner. The relationship is derived as follows. Balancing forces in the vertical direction for a symmetrical pull-up gives:

$$L = n_z W_a \tag{1}$$

Here the wing is assumed to provide the total lifting force, neglecting any control forces.

$$C_L q S = n_z W_a \tag{2}$$

$$C_{L_\alpha} (\alpha_M - \alpha_o) q S = n_z W_a \tag{3}$$

Rearranging,

$$\alpha_M q = \alpha_o q + n_z \frac{W_a}{S} \frac{1}{C_{L_\alpha}} \tag{4}$$

The angle of zero lift is normally a negative value. Therefore, neglecting it is conservative. The relation finally reduces to

$$\alpha_M q = n_z \frac{W_a}{S} \frac{1}{C_{L_\alpha}} \tag{5}$$

For the E revision of MIL-A-8591 it has been proposed that this method (equation 5) be used as the criterion for maximum αq in lieu of the constant value as specified previously. With equation (5) and the indicated aircraft design parameters, a close and slightly conservative estimate of the maximum αq value of an aircraft can be calculated, as shown in Figure (3). It would be up to the procuring agency to specify the applicable aircraft for each store or suspension system development. The store or suspension system designer would be required to obtain the requisite data. This method can be considered simply a generalization of the previous method, since αq values are still involved, and the difference is only that these must be determined for each individual aircraft of interest.

In addition to the maximum αq criterion, and assuming the relationships of the other critical maneuvers to the maximum are still valid, it is still necessary to derive expressions for two more quantities, $\alpha_R q$ and $\beta_M q$, to complete the set of airloads criteria. The expression for the incremental α due to roll rate can be derived in the same manner as was the term in the original MIL-A-8591.

$$\tan \alpha_R = \frac{V_R}{V} \quad (6)$$

$$V_R = \frac{R\,P}{57.3} \quad (7)$$

Assuming small angles,

$$\tan \alpha_R = \frac{\alpha_R}{57.3} \quad (8)$$

Then

$$\alpha_R = \frac{R\,P}{V} \quad (9)$$

But

$$q = \frac{1}{2}\,\rho\,V^2 \quad (10)$$

Assuming sea level air density,

$$\alpha_R = \frac{.0345\,R\,P}{\sqrt{q}} \quad (11)$$

Or,

$$\alpha_R\,q = .0345\,R\,P\,\sqrt{q} \quad (12)$$

At least as important as the angle of attack criteria are the angle of sideslip criteria. Applied side loads and yawing moments act in the weakest direction for the suspension equipment. Sideslip criteria have been specified similarly to angle of attack criteria by the use of a βq value. These, as with αq, have been derived from flight test results of operational aircraft. However, it is again possible to derive an expression for βq that can be evaluated with the aircraft design and aerodynamic characteristics.

The approximate analytical relationship for βq is similar to that for αq.

$$Y = n_y W_a \quad (13)$$

$$C_y\,q\,S = n_y W_a \quad (14)$$

$$C_{y\beta}\,\beta_M q\,S = n_y W_a \quad (15)$$

$$\beta_M\,q = n_y \frac{W_a}{S}\,\frac{1}{C_{y\beta}} \quad (16)$$

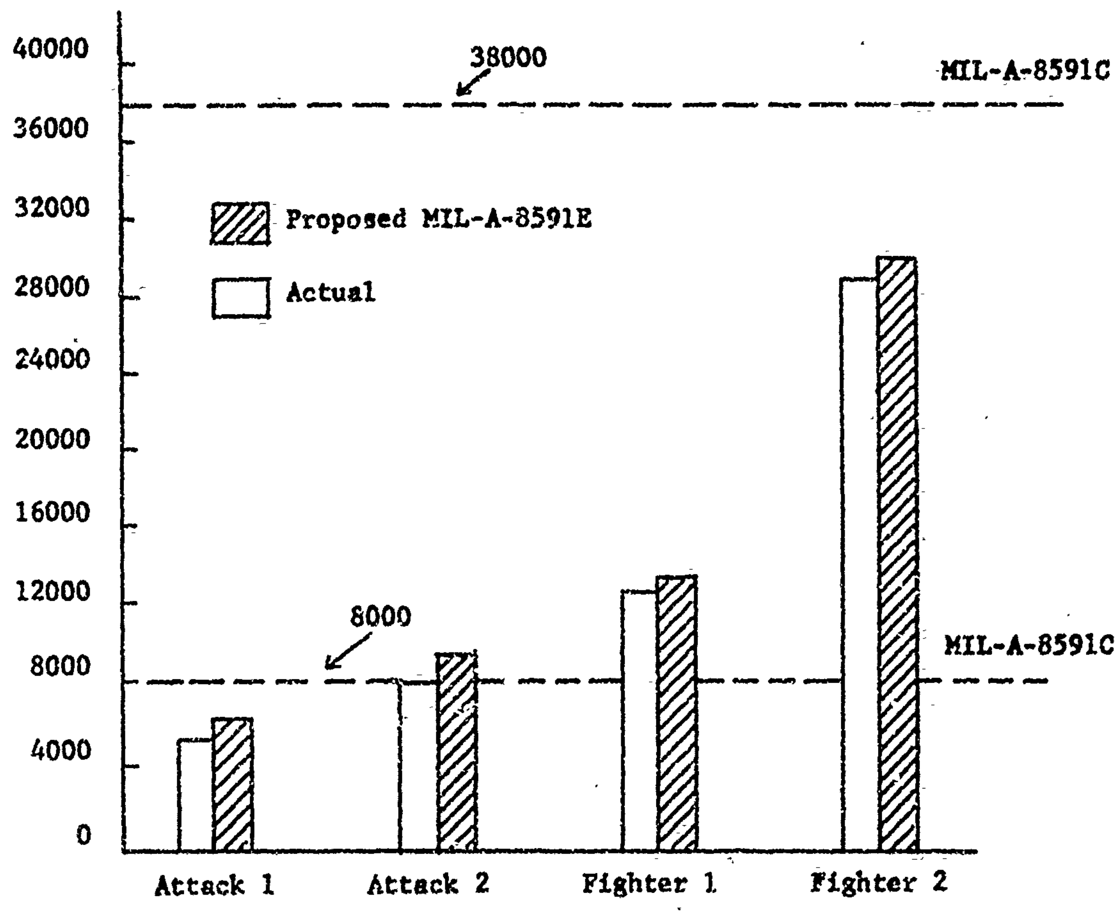


Figure 3. Comparison of Maximum σq From Proposed Criteria with Actual Values for Current Aircraft

APPLICATION

In the proposed MIL-A-8591E, the values of α_M, q, α_R q and β_M q are obtained from equations 5, 12, and 16. The ranges of α and β that must be considered with each point on the inertia load diagram are obtained from these three values in accordance with the relationships shown in Figures (4) and (5). This entire range of attitudes must be considered so that the critical combination of airloads with inertia loads will be found. If, as is sometimes the case, the effect of airloads is to subtract from inertia loads that are greater in magnitude, the critical condition is to find the lowest airloads, or neglect them entirely.

In the past versions of the specification, where a constant value of αq was specified, the only information that the designer required was the flight speed and altitude at the maneuvering condition. With the proposed revision, a set of data for the carriage aircraft is necessary. It will be the responsibility of the procuring activity to specify the aircraft for which the store or suspension equipment is to be designed. In some cases the system will be designated for a single aircraft; in other cases a limited number of specific aircraft, or it may be that only the class of aircraft (i.e. attack) is known at the time of design. If there is no designation of carriage aircraft, the design must be made to a level of strength that will permit it to be carried by any service aircraft. The level of MIL-A-8591D appears to be satisfactory for this purpose.

The specific aircraft parameter values that are required for evaluation of the criteria equations will be available in an Aerodynamic Characteristics Report for any existing aircraft. It is recognized that some cooperation on the part of the procuring agency may be necessary to ensure that the contractor can obtain the requisite information. However, to serve as a backup in the event that all or part of the information is unobtainable, a table of representative values of the parameters for several classes of aircraft is proposed for inclusion in the specification. The proposed table is shown here as Table I. The parameter values therein were derived from a survey of current operational aircraft in these classes, and, as mentioned above, are representative. The parameter values for no designated carriage aircraft, when inserted in the criteria equations, will result in the MIL-A-8591D level of criteria. To help avoid mis-application, the parameter values in this table may only be used with the approval of the procuring activity. However, when no carriage aircraft is designated, use of the indicated level therein is required.

For all points, the stores shall be considered to be mounted at incidence angles of 0 or -3 degrees, whichever is more critical in each case, to be added to the values of α_A given below:

POINTS (1) AND (2):

$\alpha_A = 0$ TO α_M DEGREES

$\beta_A = \pm 0.2\ \beta_M$ DEGREES

POINTS (3) AND (4):

$\alpha_A = 0$ TO $-0.6\ \alpha_M$ DEGREES

$\beta_A = \pm 0.2\ \beta_M$ DEGREES

POINT (5):

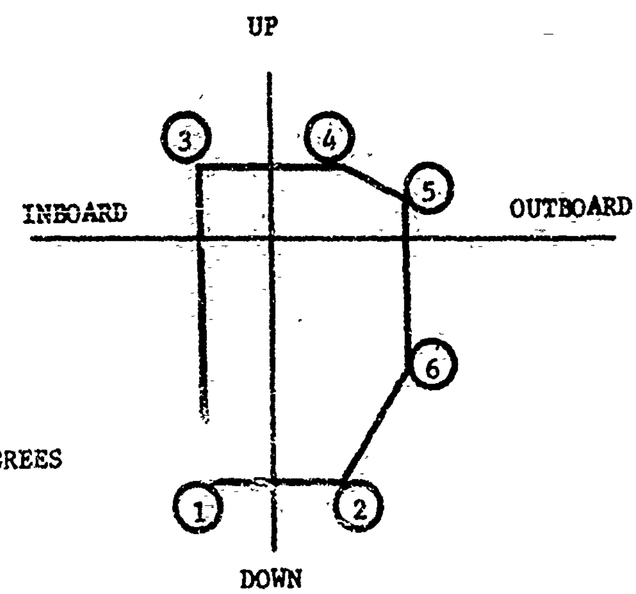
$\alpha_A = +\alpha_R$ TO $-(0.4\ \alpha_M + \alpha_R)$ DEGREES

$\beta_A = \pm\ \beta_M$ DEGREES

POINT (6):

$\alpha_A = 0$ TO $(0.8\ \alpha_M + \alpha_R)$ DEGREES

$\beta_A = \pm\ \beta_M$ DEGREES



WHERE:

$$\alpha_M = \eta_z \frac{W_A}{S} \frac{1}{C_{L_\alpha} q}$$

$$\alpha_R = .0345\ Rp/\sqrt{q}$$

$$\beta_M = \eta_y \frac{W_A}{S} \frac{1}{C_{y_\beta} q}$$

FIGURE 4. Angles of attack and sideslip for wing-mounted stores.

For all points, the stores shall be considered to be mounted at incidence angles of 0 or -3 degrees, whichever is more critical in each case, to be added to the values of α_A given below:

POINT (1):

$\alpha_A = 0$ TO α_M DEGREES

$\beta_A = \pm 0.2\ \beta_M$ DEGREES

POINT (2):

$\alpha_A = 0$ TO $0.8\ \alpha_M$ DEGREES

$\beta_A = \pm \beta_M$ DEGREES

POINT (3):

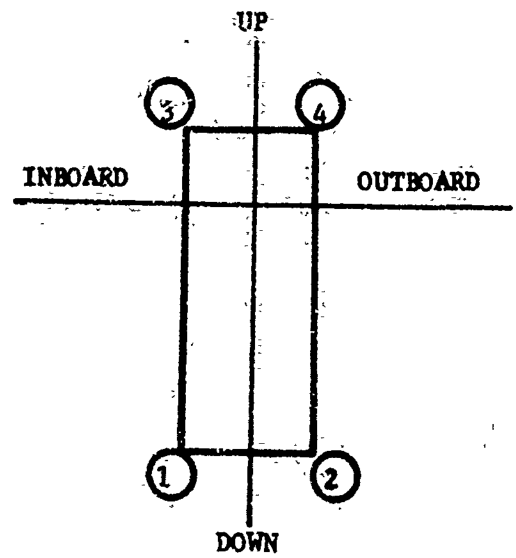
$\alpha_A = 0$ TO $-0.6\ \alpha_M$ DEGREES

$\beta_A = \pm 0.2\ \beta_M$ DEGREES

POINT (4):

$\alpha_A = 0$ TO $-0.4\ \alpha_M$ DEGREES

$\beta_A = \pm \beta_M$ DEGREES



WHERE: $\alpha_M = \eta_z \frac{W_A}{S} \quad \frac{1}{C_{L_\alpha} q}$

$\beta_M = \eta_y \frac{W_A}{S} \quad \frac{1}{C_{y_\beta} q}$

FIGURE 5. Angles of attack and sideslip for fuselage-mounted stores.

For all points, the stores shall be considered to be mounted at incidence angles of 0 or -3 degrees, whichever is more critical in each case, to be added to the values of α_A given below:

POINTS (1) AND (2):

$\alpha_A = 0$ TO α_M DEGREES

$\beta_A = \pm 0.2\ \beta_M$ DEGREES

POINTS (3) AND (4):

$\alpha_A = 0$ TO $-0.6\ \alpha_M$ DEGREES

$\beta_A = \pm 0.2\ \beta_M$ DEGREES

POINT (5):

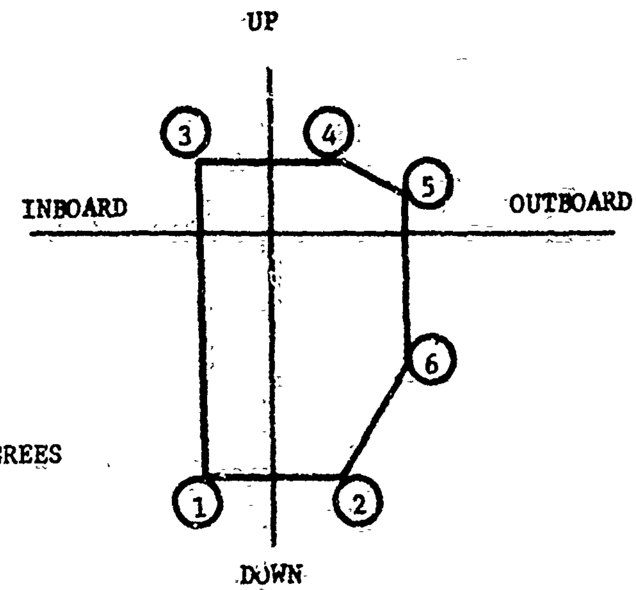
$\alpha_A = +\alpha_R$ TO $-(0.4\ \alpha_M \pm \alpha_R)$ DEGREES

$\beta_A = \pm\ \beta_M$ DEGREES

POINT (6):

$\alpha_A = 0$ TO $(0.8\ \alpha_M + \alpha_R)$ DEGREES

$\beta_A = \pm\ \beta_M$ DEGREES



WHERE:

$$\alpha_M = \eta_z \frac{W_A}{S} \frac{1}{C_{L_\alpha} q}$$

$$\alpha_R = .0345\ Rp/\sqrt{q}$$

$$\beta_M = \eta_y \frac{W_A}{S} \frac{1}{C_{y_\beta} q}$$

FIGURE 4. Angles of attack and sideslip for wing-mounted stores.

TABLE I. REPRESENTATIVE PARAMETER VALUES FOR EVALUATION OF α_M, α_R, AND β_M EXPRESSIONS

Class of Aircraft	n_Z	n_Y	P	C_{L_α}	C_{Y_β}	$\frac{W_a}{S}$	R
Navy;							
VF, VA	7.33	1.0	270	0.05	0.010	---	---
VS, VP	3.00	0.5	90	0.10	0.017	---	---
No Designated Aircraft	8.00	1.3	290	0.02	0.0095	95.0	10.0

For the aircraft weight, the Flight Design Gross Weight, as defined in reference (1), is used because it is the greatest weight at which the maximum load factor maneuver can be performed. To ensure conservative criteria, the lowest values of C_{L_α} and C_{Y_β}, where these parameters are variable (i.e. with Mach number) should be used. Since n_y is not normally an aircraft design parameter as is n_z, it will probably require calculation from the aircraft aerodynamic characteristics.

Of course, determining the aircraft angle of attack at a particular loading condition is only the first part of the problem of calculating airloads. Although the angle of attack values obtained from the specification criteria were previously labelled "store" angles, it was recognized that they represented the aircraft, not the store. The store can be considered to be mounted at either 0° or -3° to the aircraft, whichever is critical. The effects of the local flowfield as affected by the aircraft geometry, adjacent stores, and the store and suspension system itself all should be considered when the airloads are determined by theoretical or experimental means.

LUG AND SWAYBRACE REACTIONS

The most common method of supporting an external store on an aircraft is to hang it from two hooks and steady it with four swaybraces. (Sometimes, for lightweight stores, only one hook and four swaybraces are used.) At some point in the design of the system it is necessary to calculate the loads being transferred across these interfaces from the applied inertia loads and airloads on the store. This may be to complete the picture of loads on the store, or to determine the strength requirements of the suspension system. As an aid to the designer, a standardized calculation method for these lug and swaybrace reactions is included as an appendix to the specification. It should be apparent that only the standard hook and swaybrace configurations authorized by MIL-A-8591 are amenable by this analysis method; the geometrical differences of any non-standard attachment will require individual treatment.

The system of idealized lug and swaybrace reactions generally includes loads at the swaybraces which act normal to the surface of the store and loads at the store lug(s) as shown in Figure (6). The swaybrace loads are normal to the store surface because of the assumption of no friction forces. Longitudinal loads on the store are reacted at the lugs by the hooks of the rack. For a store with two lugs, it is impossible to predict the distribution of this load between the two because of tolerances. Therefore, it is assumed that all the longitudinal load is taken by the otherwise most heavily loaded lug. This assumption is conservative for loads on the lug.

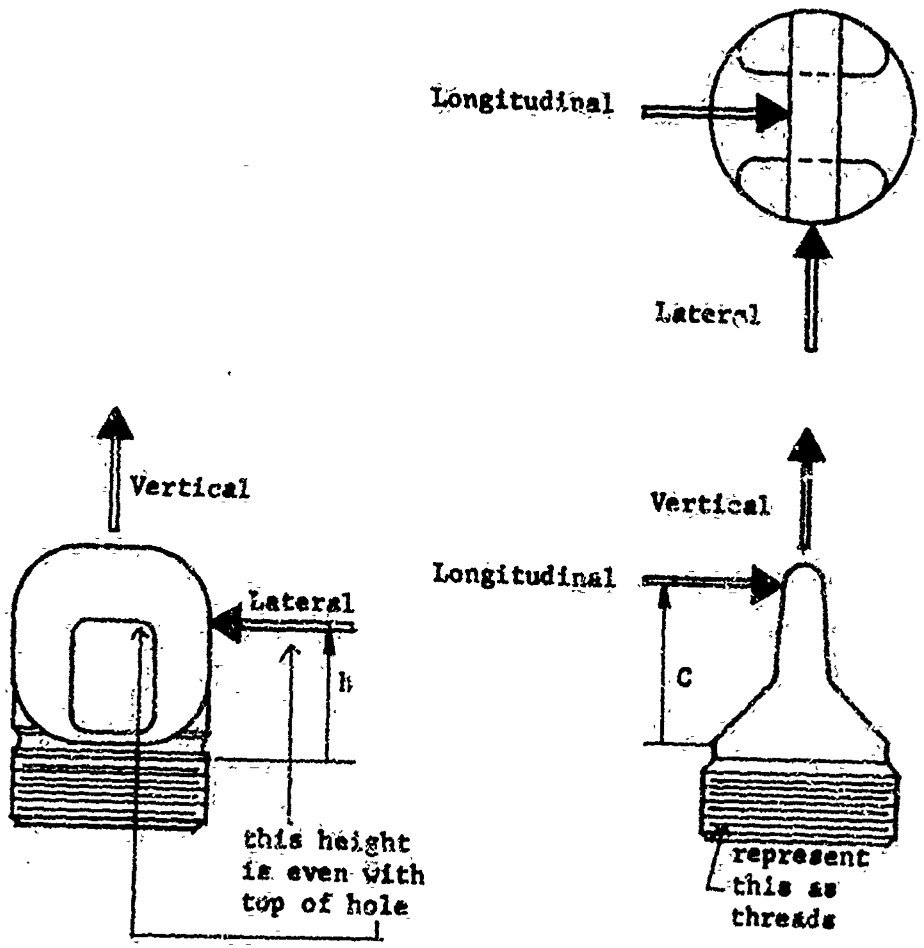


Figure 6. Action of Reaction Forces
on a Store Lug

The side load on the lug does not necessarily come from the hook, since a contemporary design uses the walls of the rack as "yaw-straps," or side reactions on the outsides of the lugs.

In the general case, the system of lug and swaybrace reactions is statically indeterminate, which means that to obtain accurate results the elasticity of the system should be taken into account. However, to simplify the method and the amount of information necessary to apply it, an assumption of the distribution of loads is included which reduces the problem to a statically determinate one. The validity of the assumptions determines the accuracy of the analysis. The two areas of indeterminacy are in the reactions to an applied yawing moment and in friction forces at the interfaces. Although friction forces are known to exist, they are neglected in the analysis without incurring significant errors. The assumed mechanism of reacting an applied yawing moment, however, is an area where substantial errors can originate.

Reactions to an applied yawing moment may be taken by opposing fore and aft swaybraces, by side loads at the lugs, or by a combination of these In MIL-A-8591, up to and including the D revision, it was assumed that no side loads were taken by the hooks, and so only the swaybraces were involved. However, in reference (2), presented at the first Aircraft/Store Compatibility Symposium in 1969, it was proposed that side loads at the hooks did, indeed, exist, and should be taken into account in the analysis. For the proposed MIL-A-8591E, therefore, the modifications proposed at that time have been included. The accuracy of the method has been improved thereby without incurring the added sophistication and complication of considering elasticity. The justification, background, and derivation of the modifications can be found in reference (2). They have been incorporated without substantial change. The fraction of the yawing moment assumed to be reacted by the lugs and swaybraces, respectively, is governed in the analysis by a load distribution factor SB. The value of SB is the fraction, expressed as a decimal, of the yawing moment which is reacted by the swaybraces. The method before modification was equivalent to the modified method with SB = 1.0.

Data from tests conducted by various installations have indicated values of SB between 0.3 and 0.6. However, since this is based solely on empirical data, it cannot be assumed that these values will be valid for all racks. There is indication that the distribution may vary with rack, store diameter, and magnitude of applied load. Although the value of SB can be specified for some specific cases; in general, it is left for the procuring agency to specify. Meanwhile, it is hoped that further work will enable a method to be derived, to be included in the specification, for determining a value of SB for a specific application.

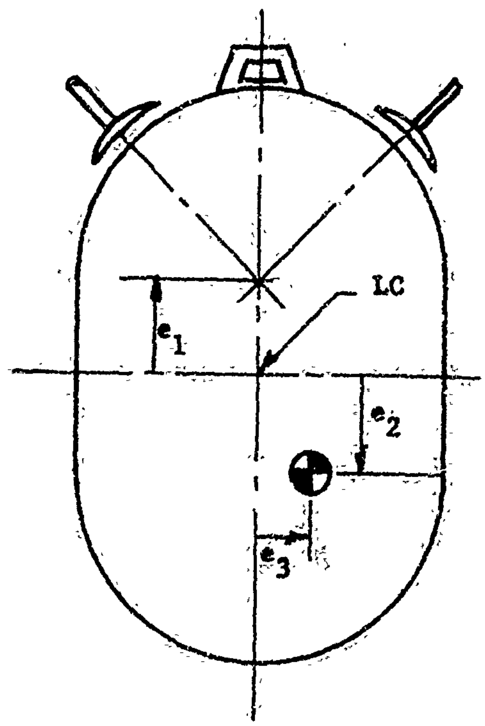
In addition to the major change described above, several updates have been made to the Appendix method. Before the E revision, applied rolling moments were not included. For some stores, such as missiles with wings, there is some significant amount of aerodynamic rolling moments. Inertial rolling moments are small enough to be negligible. Although these moments are applied to the wings and fins of the store, the simplifying assumption is made that they are applied at the station of the C.G.

A minor change in the sign and notation convention for the store cross section has been adopted as shown in Figure (7). This convention makes it possible to include all the eccentricities that may be known. In the resolving of the applied loads, it must be remembered that while inertia loads can be considered to be applied at the C.G. of the store, aerodynamic loads act on the external geometric configuration of the store without regard for the eccentricity of the C.G. Therefore, as shown in Figure (7), the external airloads are applied at the geometric center of the store, labelled the Load Center.

By proper resolution of the applied loads it is possible to treat a store/rack system that is mounted at an angle, as on the shoulder station of a MER. This capability has been inserted into the specification method. The applied loads are obtained in a coordinate system related to the carriage aircraft. By resolving them through the angle at which the rack is mounted, they can be put into a local coordinate system where the rack is apparently vertical. The normal procedure then applies. Figure (8) illustrates this transformation.

In the MIL-A-8591E Appendix calculation method, the first step is to transform the applied loads from the form in which they are given to the form required for the basic calculation. This transformation accounts for the effects discussed above: the location of applied aerodynamic and inertia loads, and any angular mounting of the store.

Because practical loadings occur in several directions simultaneously, it is not possible to decide by inspection which of several loading conditions will produce critical loads. Therefore, it is usually necessary to calculate reactions for a number of conditions. This is made practicable by the vastly increased speed of computerized analysis. Many companies and government agencies have already adapted the method of the MIL-A-8591 Appendix to a computer program. Now a computer program is included in the specification. The program is written in standard ANSI FORTRAN so as to be applicable to the widest possible range of computers. For teletype terminal application the input and output statements may require modification to conform to

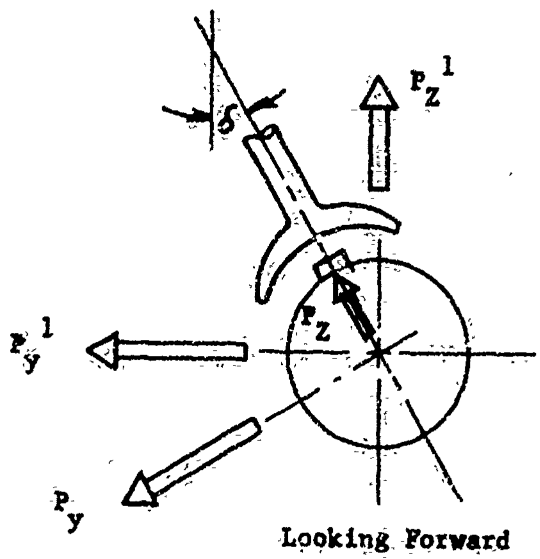


Looking Forward

Notes

1. Arrows indicate positive directions
2. LC is load center of store
3. Airloads are assumed applied at LC
4. Inertia loads are assumed applied at CG
5. Swaybrace reactions act normal to surface of store

Figure 7. Sign Convention For Eccentricities in Cross Section of Store



Primed Loads: As Applied

Unprimed Loads: Resolved to Store-Based Coordinate System

Figure 8. Sign Convention For A Store on a Rack Mounted At An Angle To Vertical

the conventions of the individual installation. It is anticipated that when the specification is released, a central distribution location for card decks of the program will be set up.

As in the earlier versions of MIL-A-8591, the reactions calculation method exists in two versions, for the standard two-lug case and for the one-lug case. The computer program also will treat either configuration. The Appendix contains a source listing of the program, a list of the symbols and notation used, instructions for inputs to the program, and sample inputs and outputs for typical problems.

SUMMARY

The Military Specification MIL-A-8591 is widely and extensively used. Its users are varied in background, and the resources and facilities available to them are likewise varied. As a general specification, it is expected to cover a wide range of configurations and applications. These factors have been kept in mind while formulating the requirements for external store design loadings in the proposed MIL-A-8591E.

An attempt has been made to incorporate in the E revision of this specification some features that will be of use to the designer and will improve the quality of the product for the procuring agency. These features, a criteria generalized for captive flight airloads that relates them to the specific carriage aircraft, and modifications to the reactions calculation method that increase both its applicability and its accuracy, have been presented for explanation, and to stimulate any dialogue, prior to actual incorporation in the official specification.

REFERENCES

1 Military Specification MIL-A-8860, Aircraft Strength and Rigidity, General Specification for; 18 May 1960; Unclassified

2 Payauys, K.W., and L.E. Rodrian; Airborne Stores and Associated Suspension Equipment Reaction Loads; published in Proceedings of Aircraft/Munitions Compatibility Symposium, Nov 1969; Unclassified

AUTOBIOGRAPHY

Mr. Seidel joined the Naval Air Development Center in 1958 as a Student Trainee. He received his B.S. degree in Aerospace Engineering in 1962 and his M.S. in 1966, both from the Pennsylvania State University. At NADC he served until 1972 in the Aero Mechanics Department as a structures engineer primarily concerned with missile developments. He was responsible for monitoring contractor performance and performing independent studies in the airframe structures area, including structural design criteria, loads, stress, aeroelasticity, and aeroheating. Projects in which he has been involved include the PHOENIX, CONDOR, and HARPOON missiles. In 1972 he joined the newly-formed Air Vehicle Technology Department as a member of the Advanced Vehicle Design Team. He is a member of AIAA and serves on the Aeroelasticity and Structures Panel of the Navy Aeroballistics Advisory Committee.

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STRUCTURAL INDICES: A TECHNIQUE FOR
USING THE COMPUTER TO RAPIDLY
ASSESS THE STRUCTURAL CAPABILITY OF AIRCRAFT
TO CARRY EXTERNAL STORES
(U)
(Article UNCLASSIFIED)

by

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Fort Worth Operation

ABSTRACT. (U) One of the major problems facing developers of modern fighter-bomber aircraft is establishment of structural flight capability while carrying "non-spec" overload external store loadings. The problem is complex from the very beginning because strength capacities of the store support structure tend to be functions of several simultaneously-acting load components. The problem is magnified when large varieties of external stores of differing shapes, weights, arrangements and, for swing-wing aircraft, differing wing sweeps are to be considered for carriage throughout large speed/maneuver envelopes.

Because of the sheer magnitude of this problem on the F-111, a computerized structural evaluation technique was developed at Convair/Fort Worth to determine stored airplane operating limits. The resulting technique is based on the use of numerical indexes of criticality for key structural components. These "Structural Indexes" are calculated by computer for a comprehensive array of structural elements over a large spectrum of airplane flight conditions. Resulting Structural Indexes can then be plotted to show trends of criticality versus Mach number, altitude, load factor, and so forth.

Experience with this technique has shown that one person can efficiently and thoroughly conduct large structural flight capability studies in relatively short periods of time.

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INTRODUCTION

A technique for rapidly assessing the capability of aircraft structures to withstand applied flight loads has been developed and is in extensive use at Convair/Fort Worth. This technique was initially developed as a tool for evaluation of the structural flight capability of external store support structures and establishment of associated allowable speed-maneuver envelopes. Since the technique was introduced, its use has been adapted to other tasks involving strength evaluation, and has been expanded to include other types of aircraft structure.

The technique developed is based on the concept of a "structural capability index" (more commonly called a Structural Index or "SI"). The Structural Index concept and its use is discussed in this paper.

HISTORICAL DEVELOPMENT

One of the major engineering problems facing the developers of modern fighter-bomber aircraft is establishing the structural flight capabilities for carrying external store loadings for which the aircraft was not specifically designed.

This problem is generally handled for all current operational fighter, attack, and bomber aircraft under a DOD-designated program called "Seek Eagle."

The problem is complex from the very beginning because strength capacities of the store support structures tend to be functions of several simultaneously-acting load components. The problem is magnified when large varieties of external stores of differing shapes, weights, and arrangements are to be considered for carriage.

The F-111 Seek Eagle program was particularly voluminous because of the variable geometry feature of the aircraft, which dictated that most store loading configurations be analyzed for up to five wing sweep angles. All problems normally encountered for fixed wing aircraft (multiple store stations, several potentially critical structural elements, large speed/maneuver envelopes) had to be dealt with for each wing sweep analyzed.

In the early stages of the F-111 program, the traditional technique of using graphical strength envelopes (backed up by detail stress analysis of a few representative load conditions) was employed to conduct structural flight capability studies of external store support structures. With this technique, applied loads are superimposed onto and visually compared with the graphical strength envelopes.

Because of the sheer magnitude of the F-111 Seek Eagle program, it was not practical to perform this task manually. The technique could have been modernized through development of computer programs which would machine-plot loads and load combinations on graphical strength envelopes. However, even if this were done, there are still at least two significant drawbacks to the visual analysis technique.

First, the examination and interpretation of loads superimposed upon graphical envelopes is a slow, and often clumsy, task. This is particularly true for strength envelopes that are based on three or more load components (multi-demensional envelopes). Such multi-dimensional envelopes are required for several types of store support structures on the F-111.

The second drawback is that the graphical envelopes readily yield only "go/no-go" information. The task of defining flight capabilities requires that definite trends of criticality be established relative to flight maneuver parameters.

STRUCTURAL INDEX DEFINITION AND BASIC USE

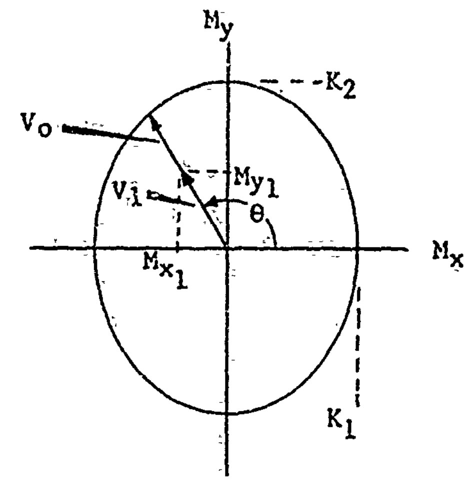
Both of these recognized drawbacks to the use of graphical envelopes can be circumvented by using a computer to calculate an "indicator number" that relates the "closeness" of any particular load condition to the boundary of a pertinent strength envelope. This is a simple process for a one dimensional envelope. All that needs to be done in that case is to calculate the ratio of a single load component to a corresponding allowable load component.

Similar "indicator numbers" can be derived almost as easily for two and three dimensional load envelopes. In these cases, ratios[1] are calculated from "vector" equations that are derived from geometric strength envelopes as illustrated in Figures 1 and 2.

The Figure 1 and 2 examples may be based on either applied loads or internal loads.

A number of other types of ratios may be used by considering the "indicator numbers" in a more general sense. The "indicator number" may be considered as the ratio of any load "quantity" to a corresponding strength "quantity". In all such applications the load "quantity" may be a single component or the vector summation of multiple "load" components such as force, moment, stress, strain, or shear flow. It is "indicator numbers" or "closeness ratios" of these general types that have been called "Structural Indices" or SI's. For brevity, "SI" will usually be used herein.

1 Stress analysts use similar ratios to calculate margins of safty; ref. Shanley and Ryder, Stress Ratios, Aviation, p. 28, June 1937; also ref. MIL-HDBK-5, pp. 15-17.



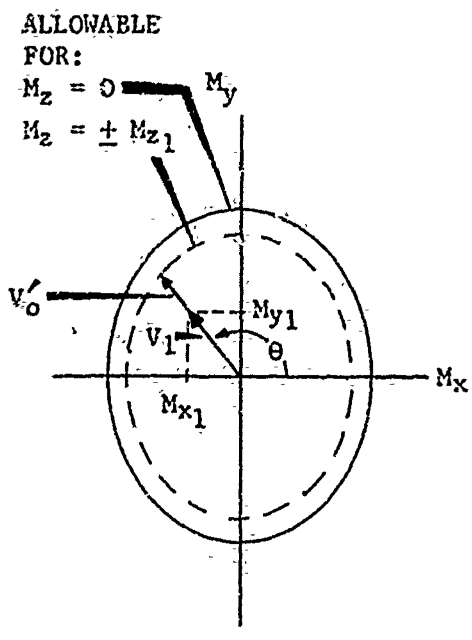
- Strength Envelope is a Function of Moments M_x & M_y
- For Load Condition M_{x1}, M_{y1}:

$$SI = V_1/V_{allowable} = V_1/V_o$$

$$= \frac{\sqrt{M_{x1}^2 + M_{y1}^2}}{\sqrt{\dfrac{K_1^2 \quad K_2^2}{K_1^2 \sin^2\theta + K_2^2 \cos^2\theta}}}$$

Where $\theta = \tan^{-1} \dfrac{M_{y1}}{M_{x1}}$

Figure 1 - Typical SI Equation Based on a Two-Dimensional Strength Envelope



- Strength Envelope is a Function of Moments M_x, M_y, M_z
- For Load Condition M_{x1}, M_{y1}, M_{z1}:

$$SI = V_1/V_{allowable} = V_1/V_o'$$

$$= \frac{\sqrt{M_{x1}^2 + M_{y1}^2}}{k(M_{z1}) \quad V_o}$$

Where:

- o V_o is defined in Figure 1
- o $k(M_{z1})$ is a strength degradation factor that is a function of M_z
- o M_{z1} is within the range of M_z for which the equation is valid.

Figure 2 - Typical SI Equation Based on a Three-Dimensional Strength Envelope

Equations and appropriate logic for calculating SI's can be derived and programmed into a computer. The computer can then calculate (in a single run) the SI's for many structural elements for a large volume of maneuver conditions.

The need to visually compare loads to any (especially multi-dimensional) strength envelope is eliminated by simply evaluating the SI's calculated by the computer procedure. This evaluation can be easily performed since, by definition, an SI gets larger as the criticality of the represented structural element increases; and SI = 1.0 when a load condition is equivalent to the limit structural capacity of the represented structural element.

Definitive trends of structural criticality can be obtained by plotting the SI's versus such items as Mach number, altitude, load factor, roll rate, and even wing sweep angle. The criticality trends can be established for individual structural elements, and more importantly for operating limitation studies, the <u>relative</u> criticality among all the structural elements can be determined. The plotting can also be done by computer.

PRACTICAL APPLICATION

In order for a structural index equation to usefully reflect structural capability, it must account for the interaction of all load components which <u>significantly</u> tax the structure when applied simultaneously. Both experience and engineering judgement are involved in determining which load components are structurally significant for the structures evaluated.

Structural index equations can be derived in two phases. Initially (Phase I), structural strength envelopes can be developed analytically. The resulting equations can then be confirmed, adjusted or replaced when pertinent structural test strength data becomes available (Phase II). With this dual approach, the theoretical analysis will often establish the basic strength envelope equation forms, while test data will be used to set the values of the constants used in the equation.

When preliminary flight limitations for the F-111 were needed before static test data was obtained, the Phase I equations were used with the customary restriction of allowing only 80% of the "unverified" structural capacity (analysis only) to be used; i.e., flight limits were defined such that the predicted SI's did not exceed 0.8. Alternately, if flight limits are not required prior to completion of static tests it may be convenient to bypass the Phase I strength definitions and go directly to "verified" strength envelopes and/or SI equations derived from structural test data.

In Phases I and II, the stress analyst has several potential sources of data (internal load, stress, strain, etc.) from which he may derive strength envelopes. Stress or strain data measured from instrumented proof test, static test or even fatigue test are obvious sources of information. Another source of potential use in this regard is data obtained during the calibration of flight test aircraft.

By using all structural strength information obtained in the normal development of an aircraft, special testing to support generation of structural index equations can be eliminated or kept to a minimum.

Figure 3 illustrates a typical type of strength envelope that could be derived from structural test data. In this example, structure was subjected to two components of load. If that same structure was subjected to a third load component, then an envelope such as shown in Figure 4 might be derived.

Analytical data can also be used in the Figure 3 approach by calculating stresses for an array of assumed load conditions.

Figures 1 and 2 illustrate that SI equations can be derived in simple fashion for two and three dimensional strength envelopes that have a familiar geometric form (an ellipse in these cases). But envelopes generated by the Figure 3 method may not conform to such familiar equation forms and SI equations are naturally somewhat more difficult to derive. Difficulty in deriving SI equations increases if more than three load components are required. But any envelope that can be drawn can also be reasonably, if not precisely, represented mathematically.

The actual drawing of graphical envelopes may not be necessary or desirable for some structures. SI equations may be derived directly from a strength "quantity" calculated from analytical equations; appropriate equations may also be derived by curve fitting test measured or analytically derived data. For the latter technique, a multiple-regression computer procedure can be useful.

Regardless of the derivation, source, or procedure, one equation may not be sufficient for proper strength definition. It may be necessary to write two or more equations for a given structure, each equation being valid for differing types of load combinations. For example, one equation could be used when two moments (M_x & M_y) are positive, another when M_x is positive & M_y negative, and so forth. For redundant structure, more than one envelope, equation or series of equations (for various load paths) is probably required with necessary logic programmed to decide which one is to be used for each particular load condition. There are many other situations and possibilities in terms of type and form of structural indexes, each requiring consideration and thought based on its own peculiar circumstances. In most cases structural index equations cannot be derived using a cook-

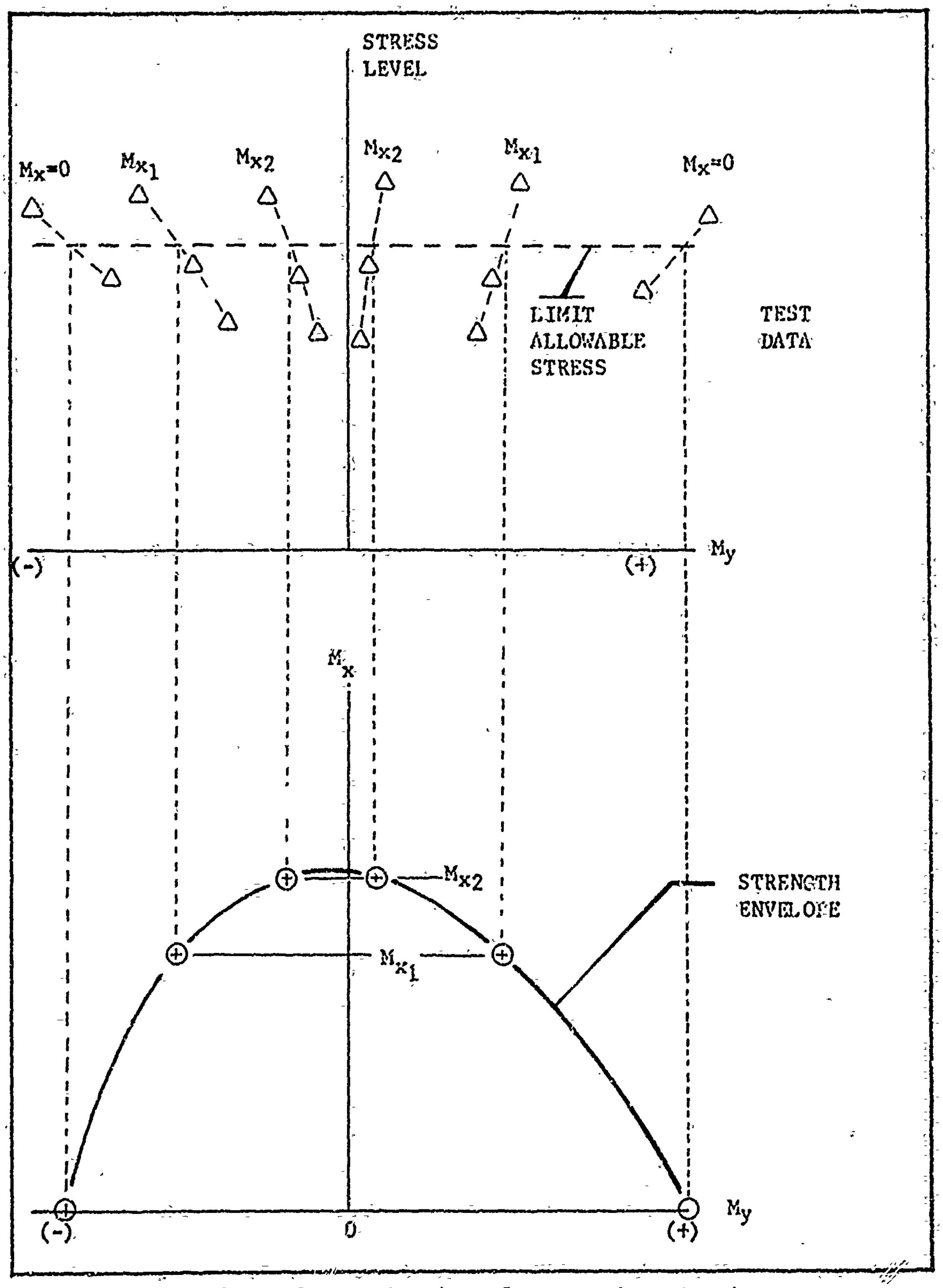


Figure 3 - Derivation of a Two-Dimensional Strength Envelope from Test Data

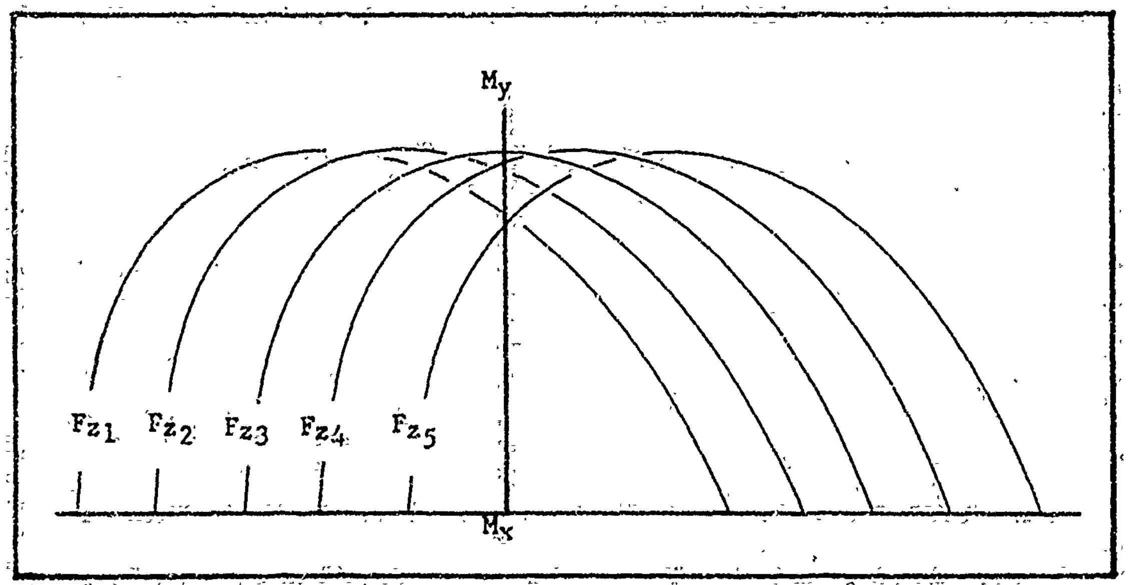


Figure 4 - A Three Dimensional Strength Envelope Derived from Test Data

book approach. The main ingredients for putting them together are innovation and logic.

STRUCTURAL INDEX USAGE

The Structural Index technique can be employed for such things as flight test (structural or otherwise) planning, quick check for "one-time-only" test flights, definition of operational aircraft structural flight capability, determination of redesign requirements, or even searches for additional flight capabilities beyond design. Because experience to this point has been most extensive in operating limits analysis, examples of the various aspects of that type of application will be used.

Data requirements for a comprehensive operating limits analysis consist of airplane and store station airloads, inertia data, maneuvering response, and structural strength definitions. This information is fed into a computerized system which computes net flight loads, compares applied loads to available strength (calculates SI values), and outputs "ordered" summaries of the structural indexes. Diagramatically, the system is shown in Figure 5.

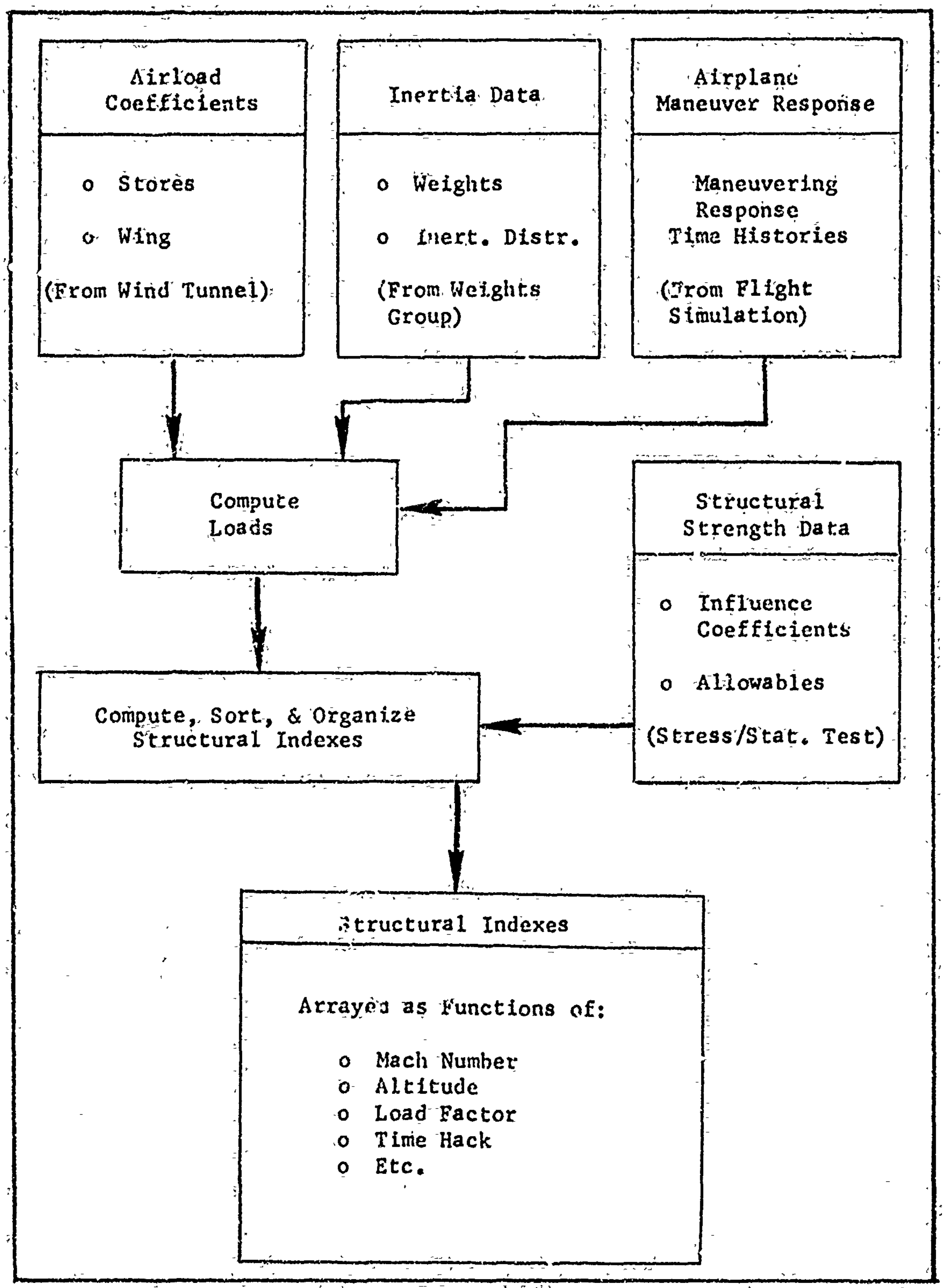


Figure 5 - Computerized S.I. System for Evaluating Structural Flight Capabilities

A typical example involves an airplane of established structural strength configured with overload "non-spec" stores, such as large, very heavy bomb clusters. Since the aircraft is not designed specifically for unrestricted carriage of such stores throughout its basic design flight envelope, it is virtually certain that restrictions will be necessary for safety of flight. For such a loading, the using military command generally has definite ideas regarding "desired" as well as "minimum acceptable" flight maneuver capability. Such goals and requirements establish ground-rules and scope of the operating limits analysis.

To illustrate one use of the structural index analysis technique for the typical overload configuration, a limited analysis of SI's will be described. The objective of the analysis described is to:

> define the structural speed limitations (assumed to be less than the "desired" speed capability) for performing unrestricted rolling maneuvers at a particular n_z entry condition.

The analysis is performed for a parametric array of Mach-altitude combinations such as illustrated in Figure 6. First, net loads are calculated using appropriate roll maneuver response data (time history) for each of these Mach-altitude points. Then, these loads are used to calculate SI magnitudes for the structural elements under study.

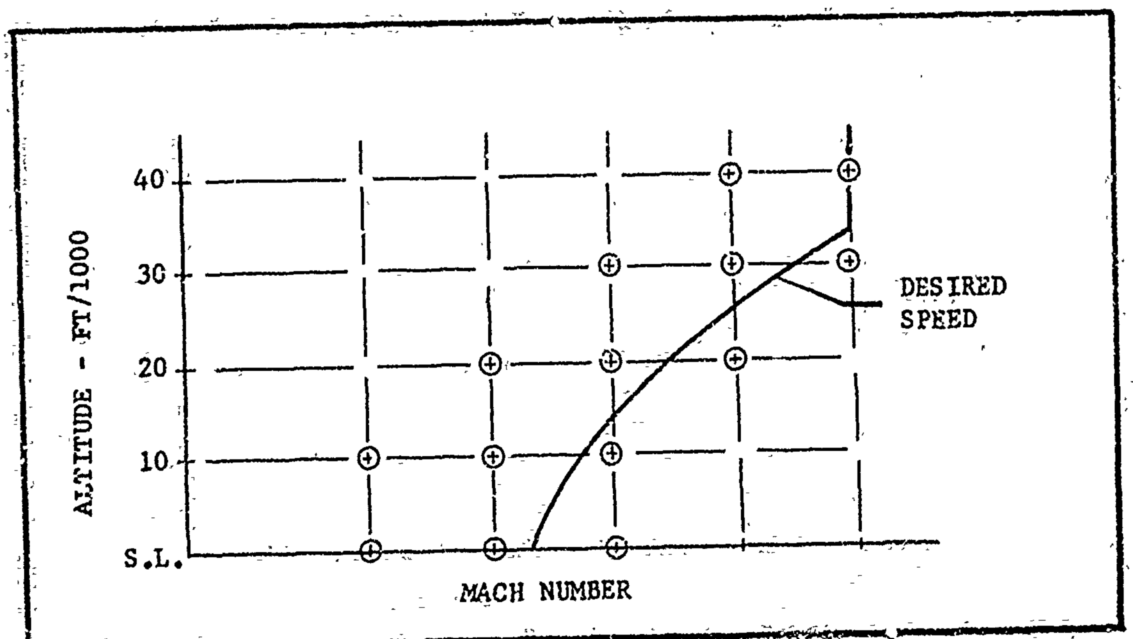


Figure 6 - Typical Mach-Altitude Grid for a Structural Index Analysis

Next, the maximum SI's that occur in each maneuver Mach-altitude condition, for each structural element, are plotted versus Mach number (at constant altitudes). The selection and the plotting can be computer-performed. And finally, the speed limits are derived from the S.I. versus Mach plots as shown by Figure 7. (The time required to perform this last step can be reduced to a minimum if the SI computer procedure is designed to select for each maneuver the maximum SI for a group of structural elements instead of for just one element.)

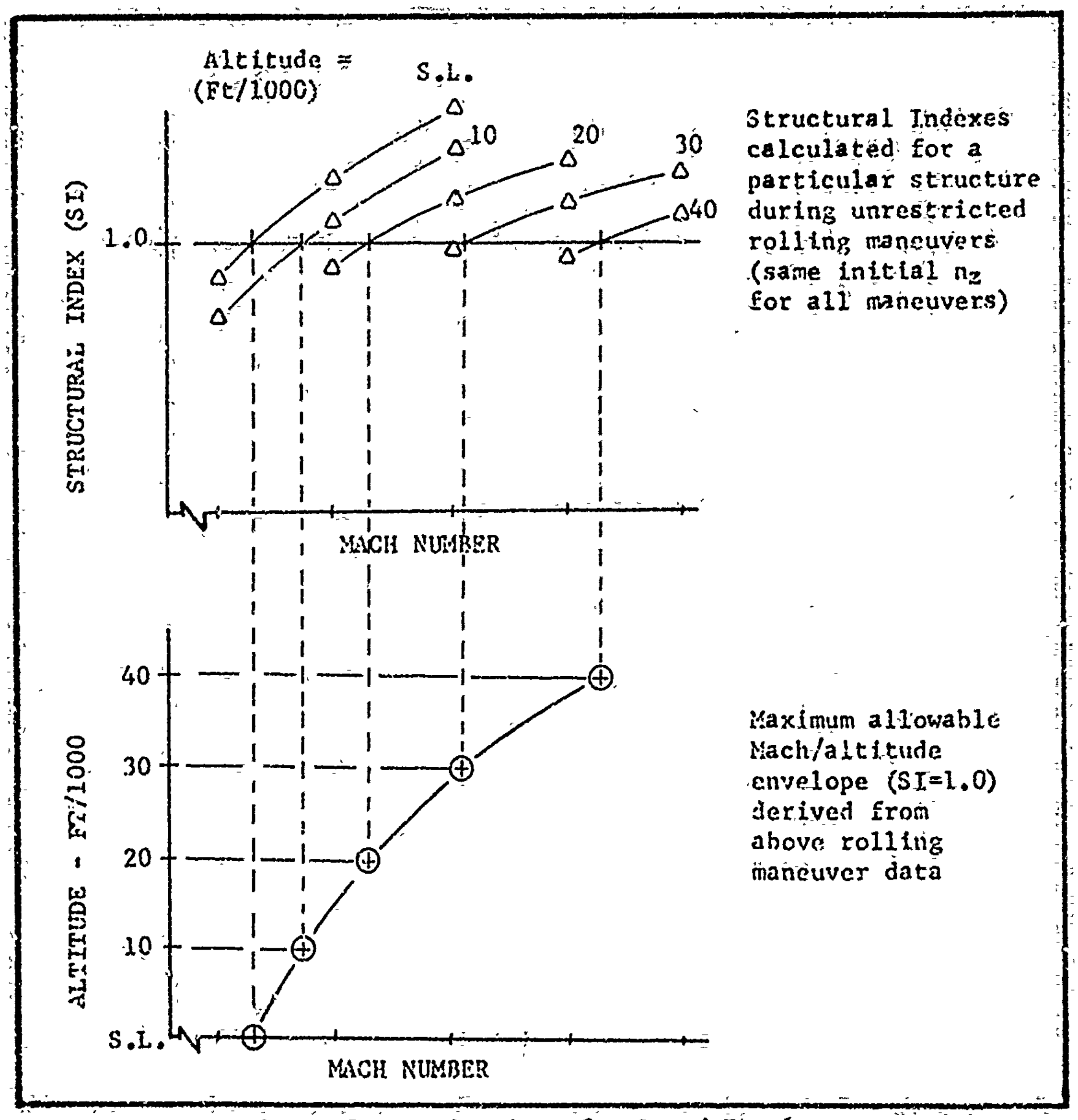


Figure 7 - Derivation of a Speed Envelope from SI Data

A complete analysis for the roll maneuvers consists of repeating the preceeding process (as necessary) for other entry n_z conditions. The final speed limits are derived by superimposing the speed limits for the individual entry n_z maneuver conditions.

If a variable wing sweep aircraft is considered in the study, then the entire process is accomplished for each sweep angle.

Many other useful studies can be performed with SI's computed for a comprehensive array of maneuver Mach-altitude conditions. Trade-off studies using an SI array can be made in order to define various combinations of speed and maneuvering limitations (allowable roll rates, bank angle changes, stick motion, airplane n_z, etc.).

Consider the situations where restrictions relative to maneuvering technique are required for a specified n_z/speed envelope. Safe limitations can sometimes be ascertained from the SI data obtained from the unrestricted maneuvering data used in the example speed restriction problem. A convenient method for analyzing this situation is to plot SI's for individual maneuvers vs time sequenced roll rate, acceleration, and/or roll angle. An SI vs roll rate plot is illustrated in Figure 8. A "safe", but not overly conservative roll rate restriction can be readily selected from this plot.

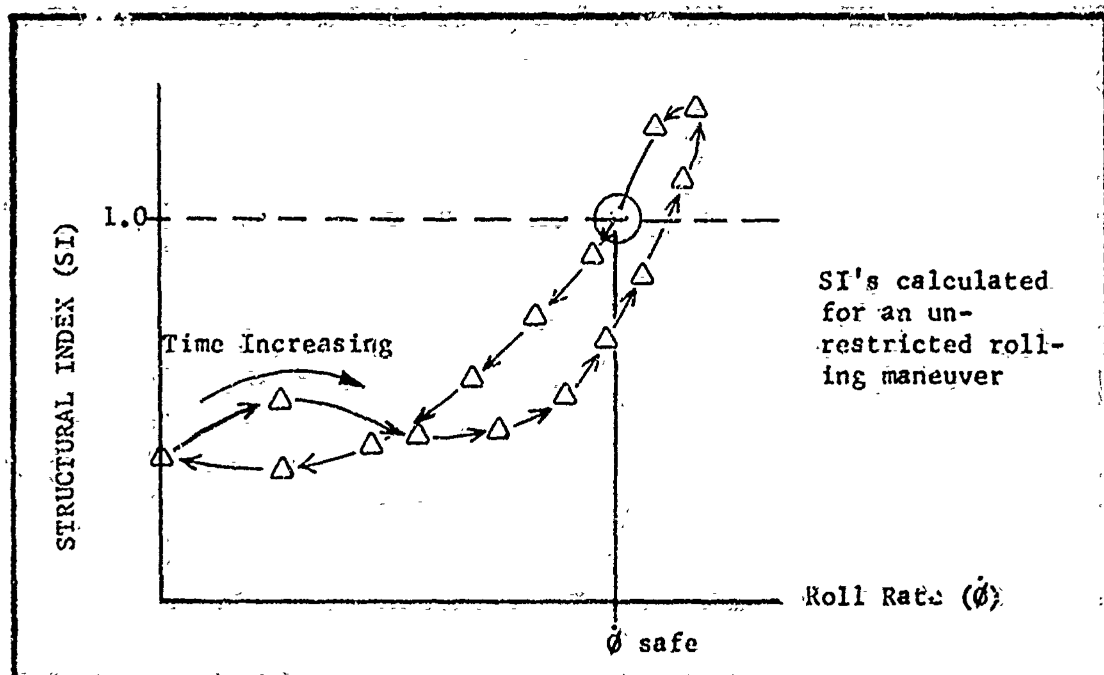


Figure 8 - Derivation of "SAFE" Roll Rate from SI Data

Another common situation is the case where it is desirable to restrict airplane rolling maneuver entry n_z so that unrestricted rolling maneuvers may be allowed. The maximum SI's used in Figure 8 can be plotted versus rolling maneuver entry n_z (for constant Mach and altitude) to determine the range of allowable entry n_z as is illustrated in Figure 9.

This section has attempted to present some basic ideas about structural index usage. Once the engineer becomes involved in trade-off studies of structural index versus speed, load factor, roll rate, etc., he will discover many different methods of data presentation to meet each particular situation.

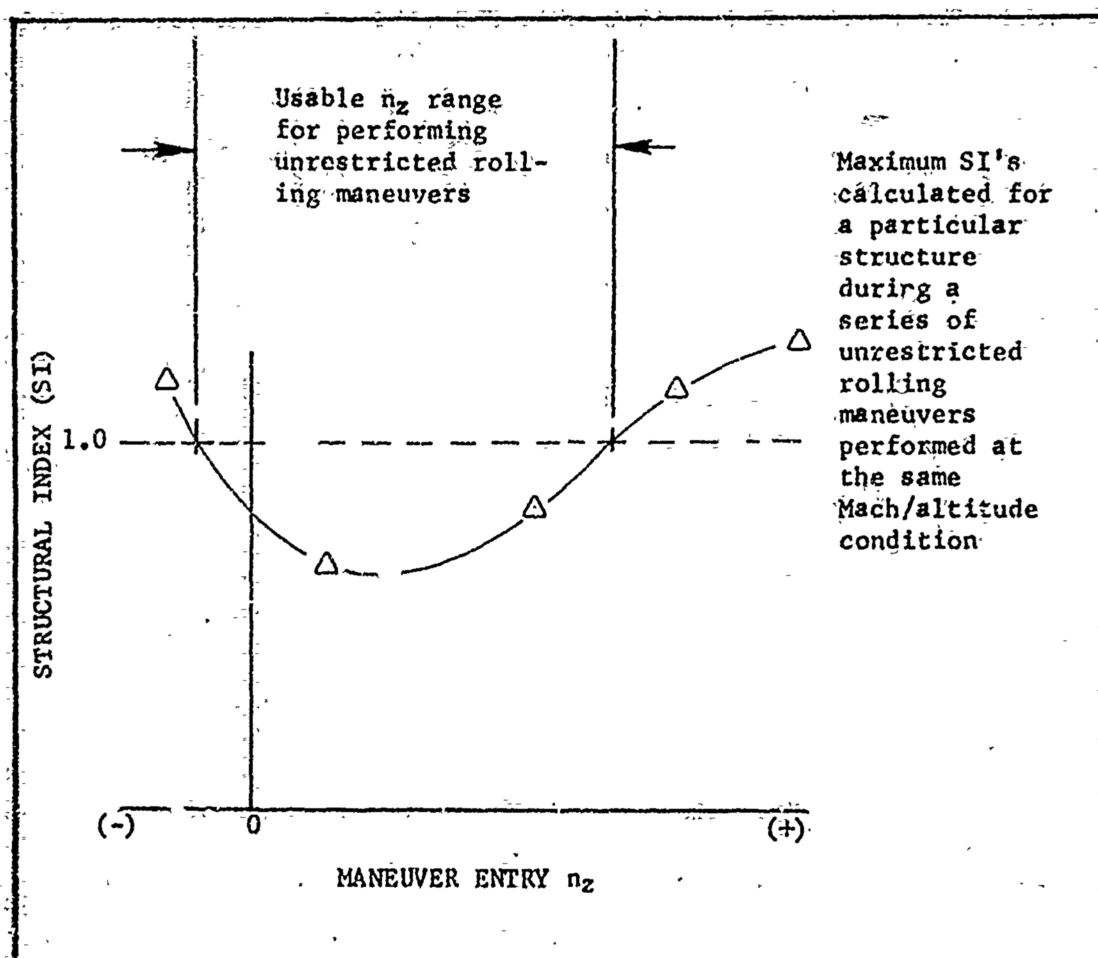


Figure 9 - Derivation of Usable n_z Range from SI Data

CONCLUDING COMMENTS

Experience with the Structural Index system developed at General Dynamics/Convair has shown that one person can efficiently and thoroughly conduct structural flight capability or limitation studies in relatively short periods of time. There are several additional points which should be mentioned, some of which should be kept in mind during development of a Structural Index System.

First, it takes a lot of preliminary thought and effort (preferably in the earlier stages of an aircraft's R & D program) to plan the system so that it is known what is expected from it. Also, it takes continued coordination with the Static Test and Stress Analysis groups in order to ascertain that the necessary strength definitions in the proper form results from their efforts. If efforts are coordinated in good fashion, the Structural Index system itself can constitute a major portion of the aircraft's Strength Summary & Operating Restriction (SSOR) report. Also, with a comprehensive SI system much of the need for long-term "detail" Stress Group support can be eliminated.

The Structural Index technique as described in this paper is ideal for large scale projects such as Seek Eagle. However, for small projects, or where "quickie-type" answers are desired, computers may not be readily available, and/or turnaround time associated with most large-scale computer operations may be prohibitive. By building on experience, it may be possible and practical to program an abbreviated form of the S.I. system onto the newer generations of desk top mini-computers. With this type of capability, it is conceivable that good answers could be provided very quickly to the questions that arise in the every day field operations of fleet aircraft.

AUTOBIOGRAPHY

BRODNAX, HUEY W.

Mr. Brodnax obtained a B.S. degree in Aerospace Engineering from the University of Texas in 1963. Since that time, he has been employed by the F-111 Structural Loads and Criteria Group of General Dynamics/Convair Aerospace Division. Serving in that group, he has had experience in most aspects of external store loads/aircraft compatibility problems. He has been responsible for the development of external store loads for the design of F-111 external store primary and secondary support structures. He also has done extensive work in the development of flight operational capability definitions for the F-111 with external stores.

RIPLEY, GEORGE R.

Mr. Ripley has been with Convair Aerospace in Fort Worth for five years. During this time he has been in the F-111 Structural Loads and Criteria Group. His responsibilities have focused on the problems involved in the structural aspects of carriage of external stores from the standpoints of weapon suspension equipment design as well as the operational capability of the aircraft/weapon system when new or different stores are installed on pre-existing structure. In this capacity he has been a principal in the development of techniques for determining aircraft structural operating capability with stores installed.

Prior to coming to Convair, Mr. Ripley was with Lockheed-Georgia Company for five years where he was in their Engineering Co-op Program in conjunction with Georgia Institute of Technology. He received a Bachelor of Aerospace Engineering Degree in 1968 from Georgia Tech, and is a registered professional engineer.

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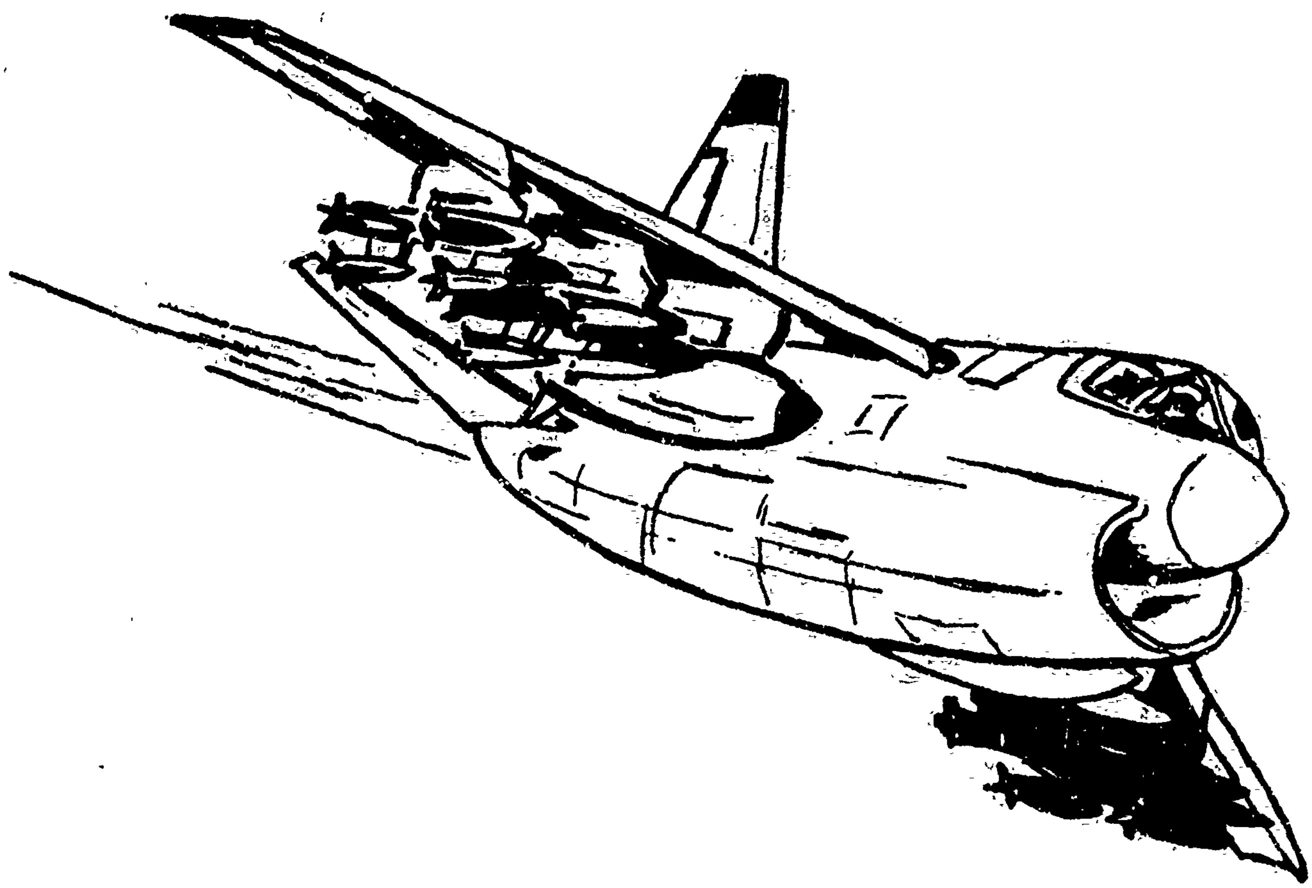
AN INVESTIGATION OF THE DYNAMIC RESPONSE OF THE A-7 AIRCRAFT TO STORE EJECTION LOADS

BY N. E. AARON and W. W. STOREY



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ABSTRACT. (U) A description is presented of the investigation of dynamic response from store ejection loads on the Vought A-7 Airplane. The primary objective of this investigation was to ensure that airframe and store structural limitations were not exceeded while releasing munitions. This paper describes the analytical methods employed during this study and compares the analytical results with measured flight test results. It was found that total aircraft response was affected by variations in airplane gross weight, entry maneuver load factor, store location, and time delay between ejections. Therefore, limitations were determined and presented as envelopes of maximum allowable entry maneuver load factor versus aircraft gross weight for the appropriate ejection cartridge force at the minimum release interval, with variations in the number and weight of bombs released. This paper also discusses an improvement in the accuracy of response analyses involving MER and TER racks achieved by employing rack influence coefficients which had been calculated from rack modal data obtained by ground vibration testing. In conclusion it is shown that the capability of analytically predicting A-7 response to store ejection loads has been definitely established based on comparisons with flight test results.

LIST OF TABLES

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LIST OF SYMBOLS AND ABBREVIATIONS

c.g.	Center of gravity
cps	Cycles per second
g	Acceleration of gravity, 386 inches per second^2
MER	Multiple Ejector Rack; an external store carriage rack used on A-7 aircraft
n_z	Airplane load factor at airplane c.g.
n_{zo}	Airplane entry maneuver load factor at airplane c.g.
q	Generalized coordinates
δ	Panel point displacement
Φ	Modal displacement
TER	Triple Ejector Rack; an external store carriage rack used on the A-7 aircraft

1.0 INTRODUCTION

The carrier-based A-7A, Corsair II, light attack aircraft has six wing pylons capable of a combined ordnance load of approximately 15,000 pounds. This aircraft was developed by Vought Systems Division of LTV Aerospace Corporation for the U.S. Navy under Contracts NOw 64-0363 and N00019-68-C-0298. Development of the land based A-7D attack aircraft for the U.S. Air Force was performed under Contract N00019-67-C-0143.

The primary objective of the investigation of dynamic response loads resulting from store ejection on the Vought A-7 Airplane was to ensure that airframe and store structural limitations were not exceeded while releasing munitions. It was found that airplane response to store ejection did impose high loadings on aircraft components during high "g" symmetrical pull-ups such as dive toss deliveries. Therefore, it was necessary to determine envelopes of maximum allowable entry maneuver load factor for various conditions of release for the large number of store loadings which comprise the A-7 attack capability. A description is presented of the methods of analysis employed during the investigation of A-7 response to store ejection. Also, results of these analytical studies are compared with measured flight test results.

There are three sources of the dynamic loading commonly known as "g" jump which is experienced by aircraft during stores release: (1) The reaction imparted to the aircraft wing by firing of ejection rack cartridges, (2) The reaction imparted to the aircraft wing by the sudden change in inertial load due to release of stores, (3) A possible magnification of these two reactions due to dynamic response of the aircraft structure. It was found that the total aircraft response was affected by variations in airplane gross weight, entry maneuver load factor, store location, and time delay between ejections. A description is presented of the analytical studies conducted to assess the effect of each of these parameters.

The mathematical model used for the investigation of store ejection response was formulated by selecting as generalized coordinates not only the required rigid body modes, but also the number of elastic structural modes necessary to define the dynamic system. It was found that for store ejection from the parent rack, the system could be adequately defined by airplane rigid body modes and a relatively small number of wing and fuselage flexible modes. However, for ejection from multiple racks it was necessary to include numerous rack/pylon elastic modes to obtain accurate results. Also, the reliability of analyses involving multiple racks was greatly enhanced by employing rack influence coefficients which had been calculated using modal data obtained from ground vibration tests of the hardware rather than from traditional static pull tests.

Flight test data obtained from the Patuxent River Naval Air Test Center provided correlation with the analytical results and verified the validity of the mathematical model used. A comparison of analytically predicted aircraft "g" jump with actual flight test measurements indicates excellent agreement over a considerable range of store weights. Based on comparisons with flight test results, the capability of analytically predicting A-7 response to store ejection was definitely established.

In summary, the basic objective of the investigation of dynamic response loads on the A-7 Airplane was achieved in that entry maneuver load factor limits were established which ensured that airframe and store structural limitations were not exceeded while releasing munitions. Based on comparisons with flight test results, the capability of analytically predicting A-7 response to store ejection was definitely established.

2.0 BACKGROUND

The basic philosophy of dynamic loads analysis employed during the investigation of the response of the A-7 Aircraft to store ejection was to determine the maximum loads for each transient loading condition. This required tuning the dynamic system to maximize the airframe response. The tuning was accomplished by using the allowable variations in the store and fuel loading, and the flight conditions. In general, parametric analyses were used to determine the tuned configuration for maximum response. A symmetric airplane representation was found to be sufficient for these dynamic loads studies as loads due to symmetric ejections of stores were shown to be more critical than the loads caused by ejection of stores alternating from side to side.

It was found that there were four variable parameters which affected total aircraft response when ejecting stores. These were: (1) Airplane gross weight, (2) Entry maneuver load factor, (3) Store location, and (4) Time delay between ejections. Each of these parameters could have wide variations over the range of store configurations considered. It was determined that restricting the entry maneuver load factor parameter was the most effective means of ensuring that structural limitations were not exceeded during store ejection. Therefore, envelopes of maximum allowable entry maneuver load factors versus airplane gross weight at minimum release interval, with variations in the weight and number of bombs released, were developed. From these envelopes, an appropriate release acceleration limit could be established for each store configuration.

3.0 MATHEMATICAL MODEL

The mathematical model employed in the aircraft response investigation consisted of both rigid body modes and also the number of component elastic modes found necessary to adequately define the dynamic system. Generally, for these studies, all modes with frequencies up to 50 cps were included. It was found that for store ejection from the parent rack, the system could be adequately defined by two airplane rigid body modes, two fuselage elastic modes, and four wing elastic modes. However, for ejection from multiple racks, it was necessary to include numerous rack/pylon elastic modes. In fact, twelve flexible modes of the MER/pylon system, as shown in Table I, were required to obtain accurate results.

The reliability of analyses involving multiple racks was greatly enhanced by employing rack influence coefficients which had been calculated using modal data obtained from ground vibration tests of the hardware rather than from traditional pull tests. Pylon and multiple rack mode shapes and frequencies calculated from influence coefficients, which had been derived from load deflection data gave poor correlation with airplane ground vibration test results. Analytical and wind tunnel test results employing these influence coefficients also did not correlate well with airplane flight test results. Therefore, a considerable technical advance was achieved when measured mode shapes and frequencies of the multiple racks loaded with various combinations of bombs were utilized together with the measured mass matrices of the combinations to analytically calculate influence coefficients. Flexible 1/7 scale racks were constructed to these coefficients, and when vibration tested on the A-7 Dynamically Similar Model gave excellent correlation with the A-7 Airplane Ground Vibration Test results. While the theory and mathematical procedures associated with this method are by no means new to the field of dynamics and have been described in detail in papers by Rodden[1] and by Hall[2], their use in dynamic loads analysis represents a significant step towards a higher degree of accuracy.

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[1] W. P. Rodden "A Method for Deriving Structural Influence Coefficients from Ground Vibration Tests," AIAA Journal, Vol. 5, No. 5, May 1967.

[2] B. M. Hall, E. D. Calkin, and M. S. Sholar "Linear Estimation of Structural Parameters from Dynamic Test Data" Proceedings of the AIAA/ASME 11th Structures, Structural Dynamics, and Materials Conference, Denver, Colorado, April 22-24, 1970.

TABLE I A-7 DIVE TOSS MANEUVER FOR 3 MK 82/MER ON OUTBOARD PYLON - AIRPLANE COMPONENT MODES AND FREQUENCIES

	COMPONENT MODE	UNCOUPLED FREQUENCY (CPS)		COMPONENT MODE	UNCOUPLED FREQUENCY (CPS)
1.	A/P RIGID BODY VERT. TRANSLATION	0	11.	3RD SYM. FLEX. PYLON/MER	19.1
2.	A/P RIGID BODY PITCH	0	12.	4TH SYM. FLEX. PYLON/MER	21.8
3.	1ST FLEXIBLE FUSELAGE	9.0	13.	5TH SYM. FLEX. PYLON/MER	30.9
4.	2ND FLEXIBLE FUSELAGE	16.4	14.	6TH SYM. FLEX. PYLON/MER	43.1
5.	1ST FLEXIBLE WING	4.0	15.	1ST ANTISYM. FLEX. PYLON/MER	2.9
6.	2ND FLEXIBLE WING	5.2	16.	2ND ANTISYM. FLEX. PYLON/MER	3.4
7.	3RD FLEXIBLE WING	11.2	17.	3RD ANTISYM. FLEX. PYLON/MER	8.4
8.	4TH FLEXIBLE WING	14.5	18.	4TH ANTISYM. FLEX. PYLON/MER	10.9
9.	1ST SYM. FLEX. PYLON/MER	5.1	19.	5TH ANTISYM. FLEX. PYLON/MER	13.9
10.	2ND SYM. FLEX. PYLON/MER	7.6	20.	6TH ANTISYM. FLEX. PYLON/MER	15.1

4.0 METHOD OF ANALYSIS

The equations of motion employed in the response analysis were formed from Lagrange's equations using the principal oscillatory modes of the dynamic system as generalized coordinates. The resulting equations may be expressed in the following form:

$$[M]\{\ddot{q}\} + [[D] + [Q_c]]\{\dot{q}\} + [[F] + [Q_d]]\{q\} = \{Q\} \quad (1)$$

where,

- $[M]$ is the generalized inertia matrix of the system
- $[D]$ is the generalized structural damping matrix of the system
- $[Q_c]$ is the generalized aerodynamic damping matrix of the system
- $[F]$ is the generalized structural stiffness matrix of the system
- $[Q_d]$ is the generalized aerodynamic stiffness matrix of the system
- $\{\ddot{q}\}, \{\dot{q}\}, \{q\}$ are the columns of generalized acceleration, velocity, and displacement, respectively
- $\{Q\}$ is the column of generalized forces associated with the generalized coordinates

Equation (1) was applied to the transient load condition by considering the generalized forces to be those resulting from oscillation of the system about an equilibrium position and those resulting from externally applied forces. The loads imposed on the airframe at the position of equilibrium were assumed to be time invariant and were added to the transient loads to give the total airframe loading.

In order to adequately define the geometry of the airframe, panel point coordinates were selected on appropriate structural components. A matrix was formulated to transform generalized coordinate displacements into panel point displacements in the following manner:

$$\delta_i = \sum_j \Phi_{ij} q_j \quad (2)$$

where,

δ_i is the panel point location at point i

Φ_{ij} is the modal displacement at point i for the jth mode

q_j is the jth oscillatory modal displacement

The resulting coordinate transformation for each airframe component was expressed as follows:

$$\{\delta\}_a = [T_{pa}]\{q\} \qquad (3)$$

where,

$\{\delta\}_a$ is the panel point displacements for component A

$[T_{pa}]$ is the panel point/generalized coordinate transformation matrix

$\{q\}$ is the generalized coordinates (A typical list of these coordinates is shown in Table I.)

Quasi-steady aerodynamic forces were used in Equation (1) in the form of $[Q_c]$ and $[Q_d]$. These aerodynamic forces were developed from two dimensional strip theory where the downwash and angle of attack were determined at convenient points on the airframe. The transient aerodynamic forces on the wing were based upon wind tunnel data consisting of the wing spanwise lift distribution, the chordwise center of pressure location, and the slope of the lift coefficient. The total airplane transient aerodynamic forces were derived from wind tunnel balance data and were imposed on the rigid body modes of the airplane.

Cartridge forces due to store ejection from wing pylons were included in the generalized forces, $\{Q\}$, of Equation (1). Time histories of cartridge force for different store weights using various types of ejection cartridges were used to determine the appropriate ejection force profile. A typical ejection force time history for the MER and TER is shown in Figure 1.

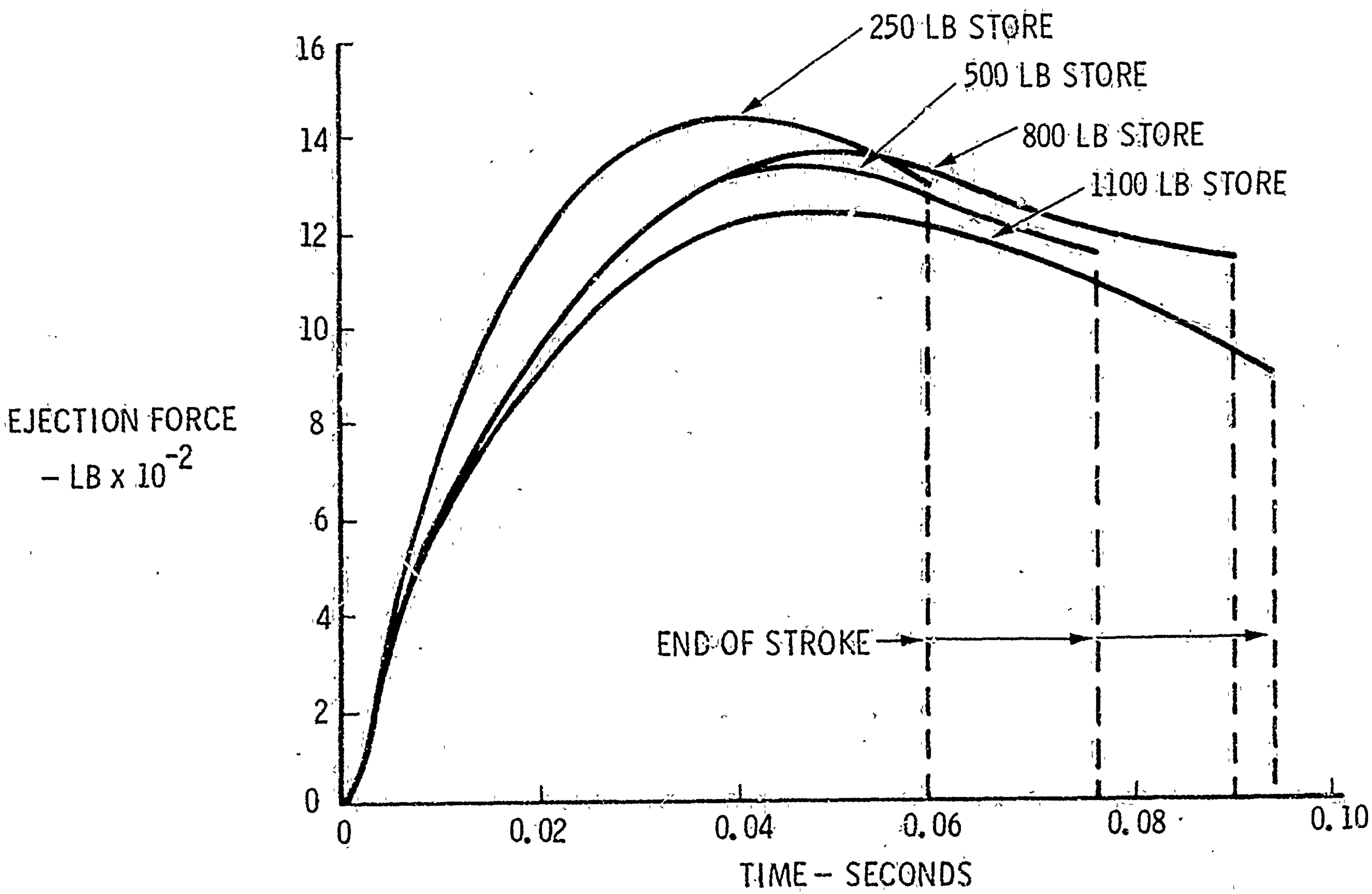

FIGURE 1 EJECTION FORCE TIME HISTORY FOR EJECTION FROM MERs AND TERs
(1 MK 2 MOD 0 CARTRIDGE)

The load equations were formulated by summing the external loads applied to the airframe. The relationship between external and internal loads was expressed by rearranging Equation (1) as follows:

$$[D]\{\dot{q}\} + [F]\{q\} = \{Q\} - [M]\{\ddot{q}\} \qquad (4)$$

Since the convergence with the number of coordinates of the right hand side of Equation (4) is faster than the left hand side, by working with the right hand side (external loads) a smaller number of degrees of freedom were required to attain the desired accuracy. The external loads thus considered were wing and pylon inertia force, wing aerodynamic loads, and cartridge forces on the pylons.

A digital computer routine was used to solve the equations of motion for the time histories of the generalized coordinates. These time histories were then substituted into the loads equations to generate time histories of the required load distributions. However, for store ejection, the equations of motion became non-linear with the dropping of a series of store masses. Therefore, a step-wise linear approach was used by formulating a series of linear equations of motion for each mass condition during the store ejection sequence. Coordinate compatibility was imposed between each set of these equations of motion so that the end conditions from the solution of one set of equations could be used as initial conditions into the succeeding set.

5.0 CRITICAL AREAS OF LOADING

Analyses of airframe component loads, using the methods described in Section 4.0, revealed that the rigid body maneuver load factor design limit or the product of load factor times gross weight (for heavy aircraft conditions) were the critical load parameters. Wing loads, pylon/rack loads, MER beam loads, and MER/TER ejector unit loads were shown to be less critical. Aircraft structural limits in the critical areas are as follows: (1) Airplane rigid body maneuver load factor design limit of 7 g's for gross weights less than or equal to 29,575 pounds, (2) Limitation of 207,025 pounds on the product of load factor and gross weight for airplane gross weights greater than 29,575 pounds. A typical time history plot of maneuver load factor obtained from the analyses is shown in Figure 2.

In Figure 2 the analytical airplane load factor time histories are shown for the ejection of 6 MK 84's mounted on each of the six airplane pylons. The MK 84's (weighing 2000 lbs. each) were ejected in pairs at 20 millisecond intervals starting with the outboard pair and working inboard.

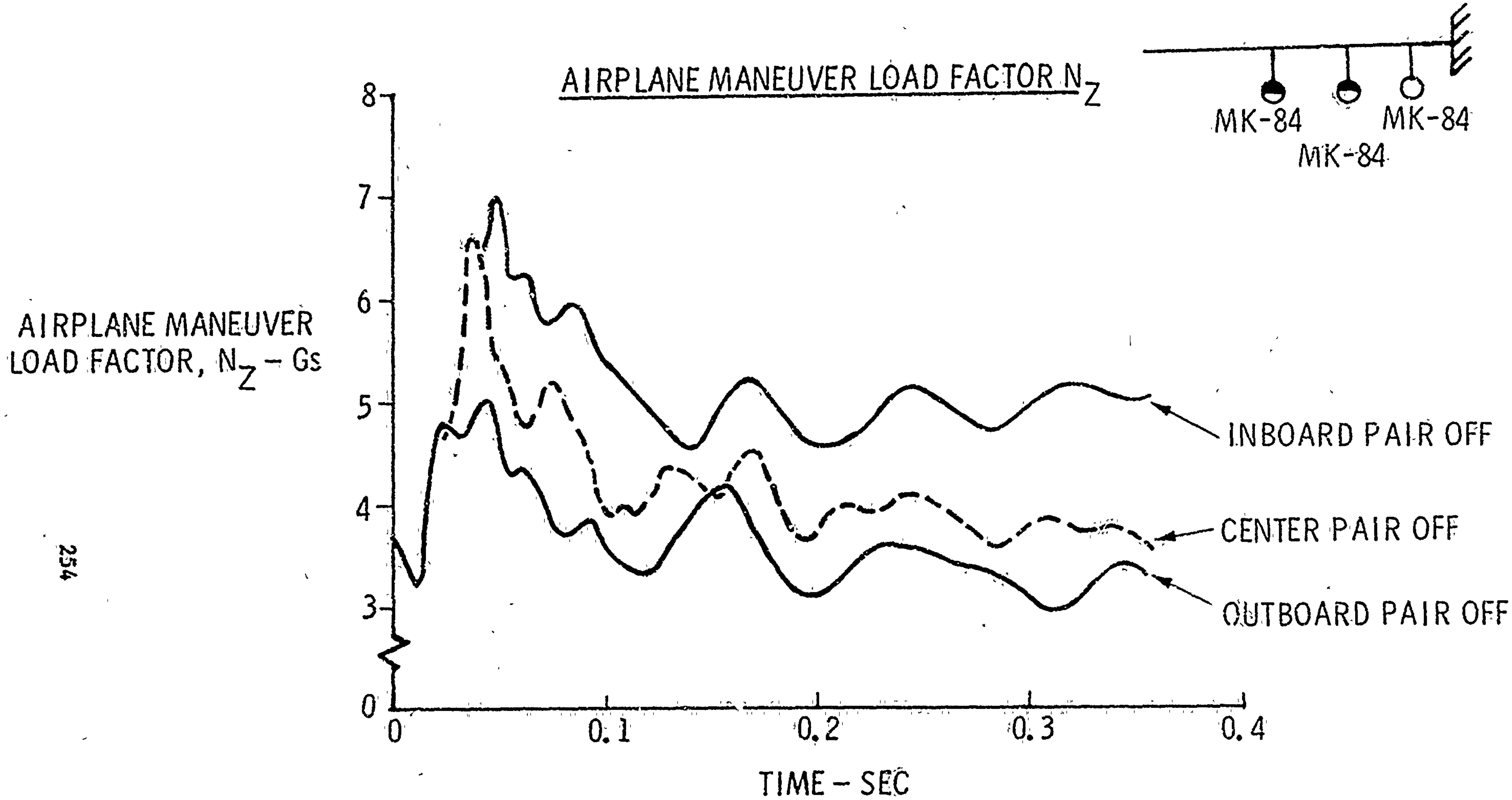

FIGURE 2 A-7D DIVE TOSS ANALYSIS AIRPLANE MANEUVER LOAD FACTOR TIME HISTORY FOR DIVE TOSS OF MK-84s FROM MAU-12B/A RACKS PAIRED RELEASES $N_{Z_0} = 3.6$ Gs

To ensure that the structural limitations were not ex .eeded during store ejection, envelopes of maximum allowable entry maneuver load factor versus airplane gross weight, with variations in the number and weight of bombs released, were determined. A typical chart of these limitations is shown in Figure 3. This figure shows entry maneuver limitations for the aircraft ejecting 2, 4, or 6 bombs each weighing between 600 and 1250 pounds. The curves break because the airplane load factor limitation decreases linearly above airplane gross weights of 29,575 pounds and the entry maneuver load factor must be reduced accordingly.

6.0 EFFECT OF RELEASE INTERVA

Considerable investigation was conducted to assess the effect of release interval on aircraft dynamic response. It was found that the smallest release time that can be achieved by the ejection system imposed the most critical load conditions. For parent rack releases, the minimum release interval attainable (most optimistic operation of the ejection system) was 21 milliseconds between symmetrically paired releases or between single releases alternating from side to side. MER/TER normal release intervals were somewhat greater, whereas the salvo ripple interval was approximately the same as the parent rack. To establish entry maneuver load factor restrictions for ejection release intervals of the parent rack other than 21 milliseconds some adjustments must be made in the limitations envelope. Table II shows the proper adjustment to be made in determining allowable entry maneuver load factor from Figure 3 for release intervals of 50, 100, and 150 milliseconds. Conversely, some extrapolation in the allowable entry maneuver load factor is possible to compensate for a reduction in the minimum release interval until the most critical loading condition, instantaneous release, is reached. It was found that only a small reduction in normal allowable entry maneuver load factor was required for instantaneous release.

7.0 ESTABLISHMENT OF FLIGHT HANDBOOK CONFIGURATION RELEASE ACCELERATION LIMITS

For each A-7 store configuration contained in the flight handbook, a release acceleration limit must be established. Some engineering judgment was involved in determining the proper "g" limit from the calculated envelopes of allowable entry maneuver factor. Using the most critical airplane gross weight for a configuration, the following factors were taken into consideration in establishing the release acceleration from the entry maneuver charts. (1) Possible number of stores released, (2) Weight of stores released, (3) Possible modes of release (paired or alternating). Using this method, release acceleration limits were established for each configuration which ensured that aircraft structural limits would not be exceeded during a dive toss delivery of stores.

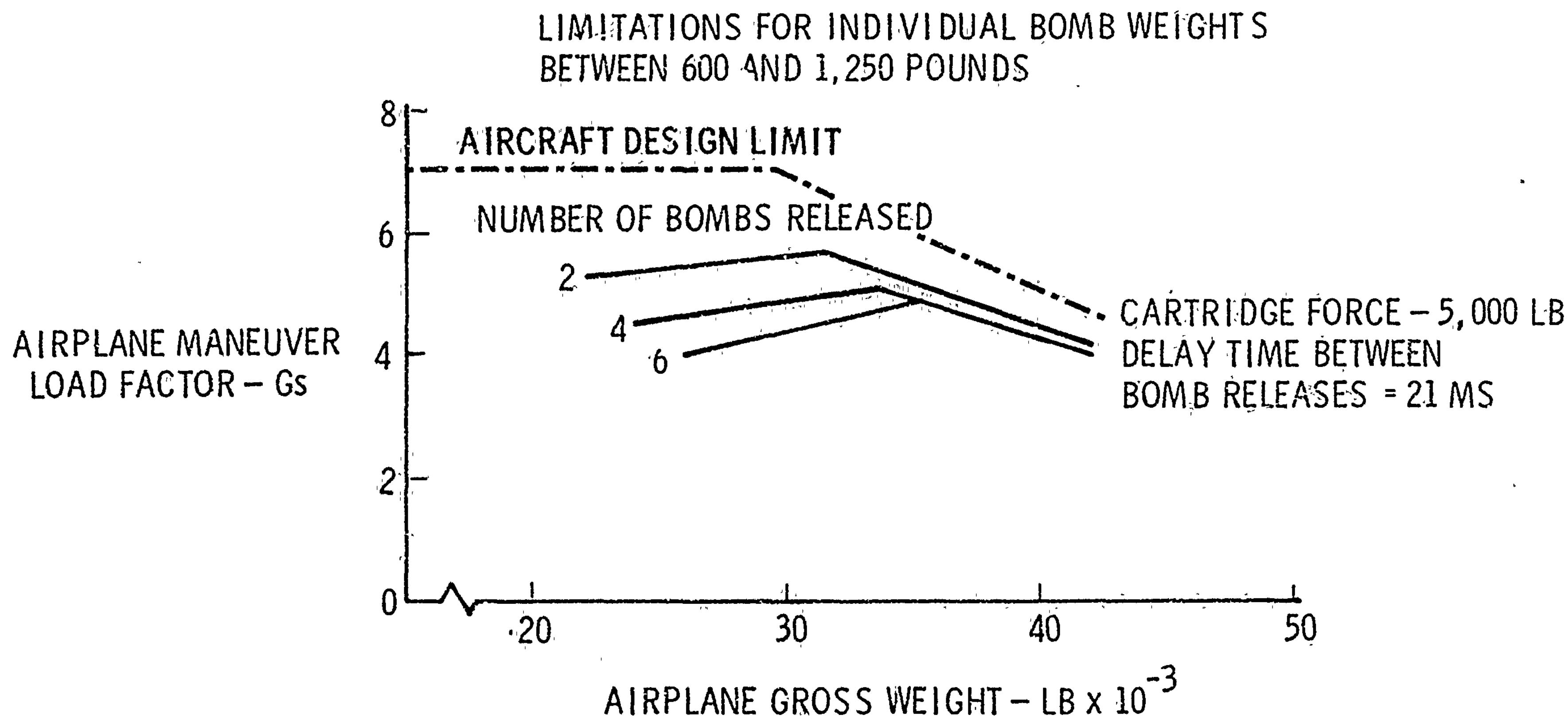

FIGURE 3 A-7D DIVE TOSS ANALYSIS MANEUVER LOAD FACTOR STRUCTURAL LIMITATIONS FOR BOMB RELEASE FROM MAU-12B/A PAIRED RELEASES

TABLE II A-7 DIVE TOSS ANALYSIS OF THE EFFECT OF TIME DELAY BETWEEN BOMB RELEASES ON MANEUVER LIMITATIONS FOR A-7 DIVE TOSS FROM MAU-12B/A OR MAU-9A/A RACKS FOR PAIRED RELEASES

NUMBER OF BOMBS RELEASED	TIME DELAY BETWEEN BOMB RELEASES, MILLISECONDS: 21 ms.	50 ms.	100 ms.
	REFER TO FIGURE 3 AS INDICATED BELOW FOR APPROPRIATE RELEASE CURVE		
2	2 BOMB CURVES	2 BOMB CURVES	2 BOMB CURVES
4	4 BOMB CURVES	4 BOMB CURVES	4 BOMB CURVES
6	6 BOMB CURVES	4 BOMB CURVES	4 BOMB CURVES

The approximate formula shown below was used to establish the trends of the limitations for variations in the store weight ejected and in the airplane gross weight.

$$(W_a - W_s) n_z = k_z (L + \Sigma F_c) \qquad (5)$$

where,

W_a is the gross weight of the airplane with stores (lbs.)

W_s is the weight of the stores ejected (lbs.)

n_z is the load factor of the airplane center of gravity due to store ejection (g's)

k_z is the dynamic magnification factor determined from flight test or analysis

L is the airplane lift (lbs.)

ΣF_c is the sum of the individual store cartridge forces (lbs)

With the assumption that the airplane lift is invariant throughout the ejection sequence, the following expression can be written:

$$L = W_a n_{zo} \qquad (6)$$

where n_{zo} is the load factor of the airplane center of gravity prior to ejection (g's)

Substituting Equation (6) into Equation (5) the following expression can be formed:

$$(W_a - W_s) n_z = k_z (W_a n_{zo} + \Sigma F_c) \qquad (7)$$

Then, by employing Equation (7), limitations on entry maneuver load factor, n_{zo} , can be set so that design maneuver load factor, n_z , will not be exceeded.

For airplane gross weights above 29,575 pounds where the limiting factor is 207,025 pounds on the product of load factor and gross weight, Equation (7) can be written as:

$$(207,025) = k_z (W_a n_{z0} + \Sigma F_c) \qquad (8)$$

8.0 LIMITATIONS FOR STORES WITH LOWER ALLOWABLE LOAD FACTORS THAN THE AIRFRAME

A unique situation arises for stores which have a lower structural load limitation than the airframe and remain captive during a dive toss delivery. It is apparent that the entry maneuver load factor must be further reduced to prevent the allowable load limit of these stores from being exceeded. The following relationship was used to determine the appropriate release limitation:

$$n_{zo_s} = n_{zo_{ap}} - (n_{z_{ap}} - n_{z_s}) \qquad (9)$$

where,

n_{zo_s} = maximum maneuver entry load factor, in g's to maintain store load factor for a store in captive flight

$n_{zo_{ap}}$ = maximum entry maneuver load factor, in g's, without store restrictions

$n_{z_{ap}}$ = airplane total maneuver load factor restriction, in g's

n_{z_s} = load factor restriction of the store in g's

Note that Equation (9) gives conservative limitations since the more precise relationship is as follows:

$$n_{zo_s} = n_{zo_{ap}} - \left(\frac{W_{ap} - W_s}{W_{ap}} \right) (n_{z_{ap}} - n_{z_s}) \qquad (10)$$

where,

W_{ap} is the airplane gross weight prior to store ejection (lbs.)

W_s is the store weight ejected (lbs.)

Since the term $\frac{Wap - Ws}{Wap}$ is always between 0.5 and 1.0, the load factor, n_{ZOS} from Equation (9) would be somewhat lower than from Equation (10). However, due to ease of application, Equation (9) was used to set the limitations.

9.0 CORRELATION WITH FLIGHT TEST RESULTS

Flight test data obtained from the Patuxent River Naval Air Test Center provided correlation with the analytical results and verified the validity of the mathematical model used. A comparison of analytical prediction of the expected aircraft "g" jump with actual flight test data is shown in Table III and indicates excellent agreement over a considerable range of store weights for parent rack releases. A more complete picture of correlation of analytical results with flight test results was obtained on an instrumented drop of MK 84 bombs from an Air Force A-7D. On this flight, six MK 84 bombs were pair released from a 36,100 pound airplane (including store weights) at an initial maneuver load factor of 3.6 g's. Analytical and experimental time histories of airplane response are compared in Figure 4. It can be noted from Figure 4 that at a fuselage station near the airplane center of gravity the peak vertical acceleration for the analytical results is practically identical to that measured during the flight test. Based on these comparisons with flight test results, the capability of analytically predicting A-7 response to store ejection was established.

10.0 SUMMARY AND CONCLUSIONS

It was found that A-7 Airplane response to store ejection loads imposed high loadings on structural components during high "g" symmetric pull-ups such as dive toss deliveries. Therefore, an analytical investigation was conducted to determine maximum allowable entry maneuver load factors for various conditions of release for the large number of store configurations which comprise the A-7 attack capability. A description has been presented of the methods of analysis employed during this investigation of A-7 response to store ejection. Also, results of these analytical studies have been compared with measured flight test results.

TABLE III COMPARISON OF ANALYTICALLY PREDICTED "g" JUMP WITH MEASURED FLIGHT TEST RESULTS

CONFIGURATION	ANALYTICALLY PREDICTED "g" JUMP	MEASURED FLIGHT TEST "g" JUMP
(1) MK 82 LDGP STA 1, 2, 3, 6, 7, 8	2.7 g *	2.4 g **
(2) MK 83 LDGP STA 1, 2, 3, 6, 7, 8	2.8 g *	2.9 g **
(3) MK 84 LDGP STA 1, 2, 3, 6, 7, 8	2.3 g *	2.4 g *

* From: VSD Report 2-53800/9R-5467 "A-7A/B Airplane New Store Capability Program Dynamic Loads Report" dtd 15 August 1969

** From: NAVAIRTESTCEN PAXRIV MSG 192143Z Oct 72

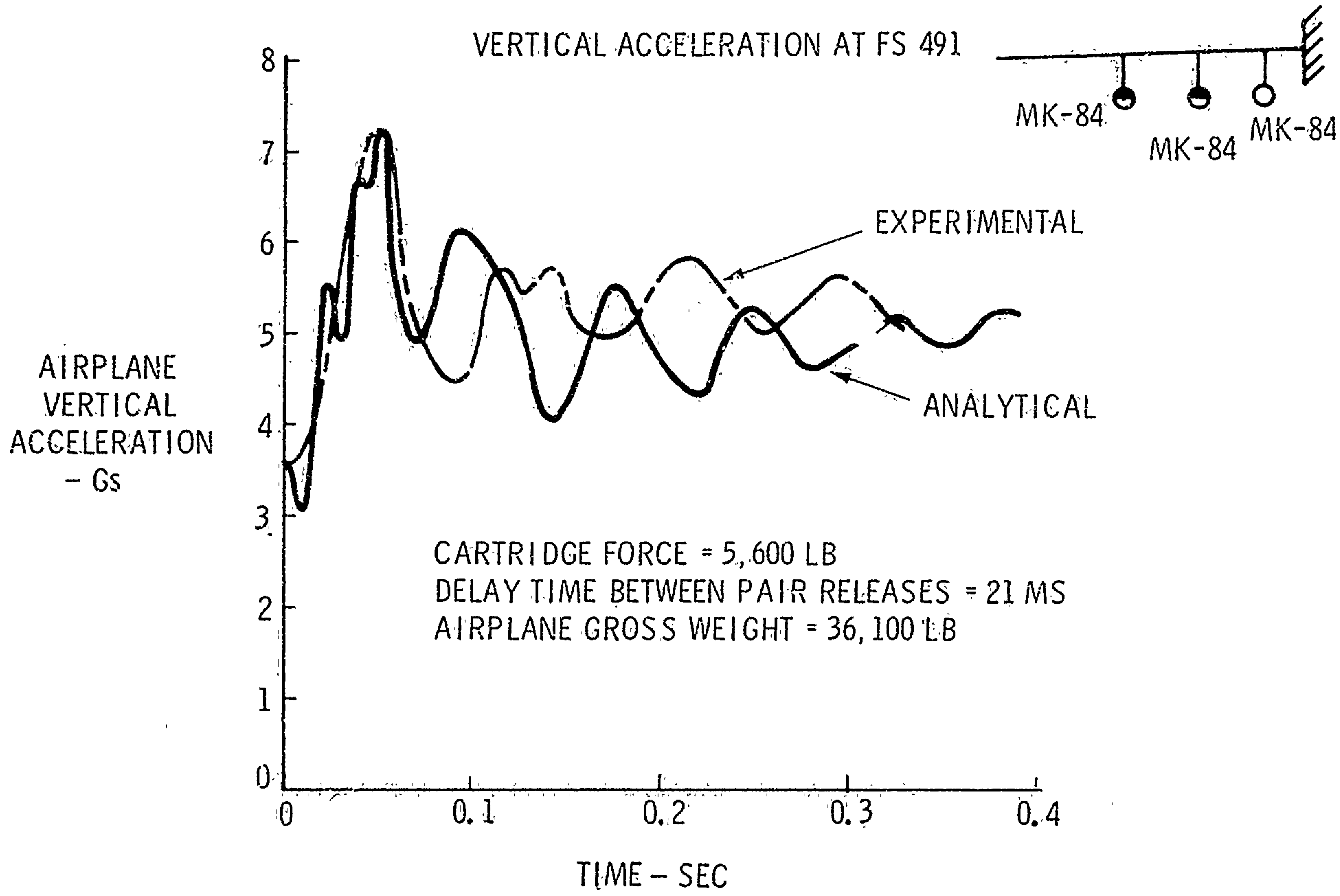

FIGURE 4 A-7D DIVE TOSS ANALYSIS FLIGHT TEST CORRELATION CASE VERTICAL ACCELERATION OF FS 491 BULKHEAD DURING DIVE TOSS OF MK-84s FROM MAU-12B/A RACKS PAIRED RELEASES N_{Z_0} = 3.6Gs

In conclusion, the primary objective of the investigation of dynamic response loads on the A-7 was achieved in that limitations were established which ensure that airframe and store structural limitations are not exceeded while releasing munitions. The accuracy of ejection response analyses involving MER and TER racks was greatly improved by employing rack influence coefficients which had been calculated using rack modal data obtained by ground vibration testing. Finally, based on comparisons with flight test results, the capability of analytically predicting A-7 response to store ejection was definitely established.

AUTOBIOGRAPHY

Norman E. Aaron

Mr. Aaron is currently Structural Dynamics Project Engineer for the Cruise Missile Project. Prior to this, from 1971-72 he was Technical Project Engineer for Structural Dynamics R&D. In this function he directed and monitored the R&D effort for the Structural Dynamics Group. From 1965-70 Mr. Aaron was A-7 Dynamic Loads Project Engineer where he was responsible for all dynamic loads analyses and tests on the A-7 Programs. The major part of this effort consisted of loads for store release, carrier landings, canopy jettison, major equipment items, and gust. From 1962-64 he directed and coordinated the dynamic loads effort on the XC-142 V/STOL Airplane. Prior to joining Vought in 1962, he was a dynamic loads engineer with the Boeing Company from 1958 to 1962.

Mr. Aaron received his B.S. in Mathematics from the University of Massachusetts in 1953 and his M.S.E. in Engineering Mechanics from the University of Michigan in 1958. He is a registered Professional Engineer in the State of Texas.

AUTOBIOGRAPHY

W. W. Storey

Mr. Storey attended Rice University in Houston, Texas, and received a B.S. degree in Chemical Engineering in 1958. He joined the Structural Dynamics Group of Vought Aeronautics in 1961 after service in the U.S. Navy as Chief Engineer on a destroyer escort. Since that time his experience has included work on such varied projects as a large parabolic radar antenna, the Lance Missile, and F-8 and A-7 Aircraft. At the present time his primary responsibilities are flutter and dynamic loads analyses, ground testing, and flight flutter testing on A-7 series aircraft. He is a Registered Professional Engineer and a member of the American Ordnance Association.