DEPARTMENT OF THE NAVY
NAVAL AIR WARFARE CENTER, AIRCRAFT DIVISION
OFFICE OF COUNSEL
47076 LILJENCRANTZ ROAD, BLDG 435
PATUXENT RIVER, MD 20670-1127

IN REPLY REFER TO

5720
Ser NAVAIR-11.5C/FD09-0371
01 October 2009

Mr. John Greenewald, JR.
[redacted]

Dear Mr. Greenewald:

This letter is in final response to your 9 September 2009, Freedom of Information Act (FOIA)[1] request for a copy of the following documents:

(1) "Study of Methods of Range Extension of Carrier Based Jet Fighters by Carrier Based Assisting Aircraft dated Jul 1950, Accession number AD0223931

By CNO ltr. 5720 , Ser DNS-36C/9U111902 dated 17 Aug 2009, item (1) was forwarded to Department of Defense, Defense Technical Information Center (DTIC).

By DTIC-R ltr (FOIA 2009-167) dated 4 September 2009, your request and the responsive document was forwarded to this command for review and release determination.

We have conducted a security review of DTIC report number AD223931 entitled "Study of Methods of Range Extension of Carrier-Based Jet Fighters by Carrier-Based Assisting Aircraft" dated Jul 1950. The attached document has been formally declassified and is released in its entirety.

All costs associated with the processing of your request are waived because they do not exceed $15.00.

---

[1] 5 U.S.C.S. § 552.

Please contact me by telephone at (301) 342-9564, by facsimile at (301) 342-1292, or by email at ruth.yates@navy.mil if you have any questions regarding this matter.

Sincerely,

RUTH B. YATES
Freedom of Information Coordinator
Naval Air Systems Command Headquarters
47076 Liljencrantz Road, Bldg. 435
Patuxent River, MD 20670

Copy to:
Defense Technical Information Center
Attn: Mr. Michael A. Hamilton
Acting FOIA Program Manager
8725 John J. Kingman Rd. STE. 0944
FT. Belvoir, VA 22060-6218

Study of Methods of Range Extension of Carrier-Based Jet Fighters by Carrier-Based Assisting Aircraft

BUREAU OF AERONAUTICS (NAVY) WASHINGTON DC

JUL 1950

A## 4

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RESEARCH DIVISION

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NAVAER

STUDY OF METHODS OF RANGE EXTENSION OF CARRIER-BASED JET FIGHTERS BY CARRIER-BASED ASSISTING AIRCRAFT

DR REPORT NO. 1197

Navy Dept. July 1950 BuAer

Prepared by JOHN E. FORRY

Approved by ABRAHAM HYATT
Head,
ADR Branch

Approved by IVAN H. DRIGGS
Director,
Research Division

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TABLE OF CONTENTS

INTRODUCTION AND SUMMARY

The Research Division has conducted a study of a number of methods for extending the range and endurance of carrier-based jet fighter aircraft by the use of carrier-based assisting aircraft. While the major object of the study was to determine and compare the performance benefits which could be obtained, the foreseeable technical and operational problems were also given some consideration.

In the interests of expediency, this work has been confined to four current airplanes, F9F-5 and F2H-2 fighters, and AD-4 and AJ-1 assisting airplanes. The latter two types are used in the role of tow and refueling airplanes. Note that all four are straight wing types; the results of this study should not be extrapolated to swept wing types.

The results indicate that three of the methods studied, wing-tip towing, flight refueling, and cable towing, are to all practical purposes equal in range gains. Wing-tip towing is subject to a number of unfavorable considerations, two of which are:

a. It requires very high powers of the tow planes -- 85% to 90% of normal rated power for the first portion of the flight.

b. The calculated performance is the least reliable because of uncertainty of the aerodynamic effect of wing-tip linking on induced drag.

In a comparison on a technical basis, flight refueling is attractive be-

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cause of the background of experience already at hand. However, it appears that wing-tip towing offers no insurmountable difficulty, given some reasonable development effort.

Operationally, all of the methods considered required that two or more airplanes make physical contact in mid-air. However, the towing methods offer the advantage of early rendezvous, near the carrier, while flight refueling, as studied here, requires a rendezvous between tanker and fighters as much as 1200 nautical miles from the carrier in extreme cases.

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RESULTS AND DISCUSSION

1. Scope

The following combinations were investigated:

a. Like-fighters linked

(1) Out and back

(i) Three fighters with adjacent wing-tip tanks removed

(ii) Three fighters with adjacent wing tip tanks not removed

(2) Linked out, single back

(i) and (ii) Same as (1) above

b. Two like-fighters towed by one tow plane.

(1) Wing tip tow out, all fighter tip tanks in place

(2) Wing tip tow out and back, all fighter tip tanks in place.

(3) Cable tow out only

(4) Cable tow out and back

c. Fighters refueled by tankers

(1) One fighter per tanker

(2) Two fighters per tanker

d. Two like-fighters towed at maximum endurance speed to extend fighter endurance.

(1) Fighters heavy (before mission)

(a) Wing tip tow

(b) Cable tow

(2) Fighters light (after mission)

(a) Wing tip tow

(b) Cable tow

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2. Performance

The resulting gains in range and endurance are summarized for the F9F-5 in figure (1) and for the F2H-2 in figure (2). The most significant general conclusion is that wing-tip towing, flight refueling, and cable towing are quite comparable, as follows:

	Combat Radius - n. mi.					
	Wing-Tip Towing		Flight Refueling		Cable Towing	
Operation \ Fighter Type	F9F-5	F2H-2	F9F-5	F2H-2	F9F-5	F2H-2
Single Airplane Unassisted	600	717	600	717	600	717
AD-4 Assisting two-fighters on outbound leg	825	935	770	815	770	890
AJ-1 Assisting two fighters on outbound leg	1000	1240	1000	1150	825	940

In the case of wing-tip towing, very high powers are required of the two planes, the AD-4 at start of tow using 90% of normal rated power, at end of tow, 80%; and the AJ-1 using 85% and 60% for the same two conditions. If the two planes are unloaded to reduce the cruise power requirements to 60% of normal rated power, or below, at all times, the wing tip tow is less efficient than flight refueling.

Each of the comparable methods summarized above requires one assisting plane for each two fighters except flight refueling, where three fighters may be refueled by a single tanker. However, if the case of two fighters being refueled by a single tanker is chosen for comparison, wing-tip towing, flight refueling, and cable towing all require the same ratio of assisting to fighter aircraft. Therefore, a direct comparison of combat radius extension seems to

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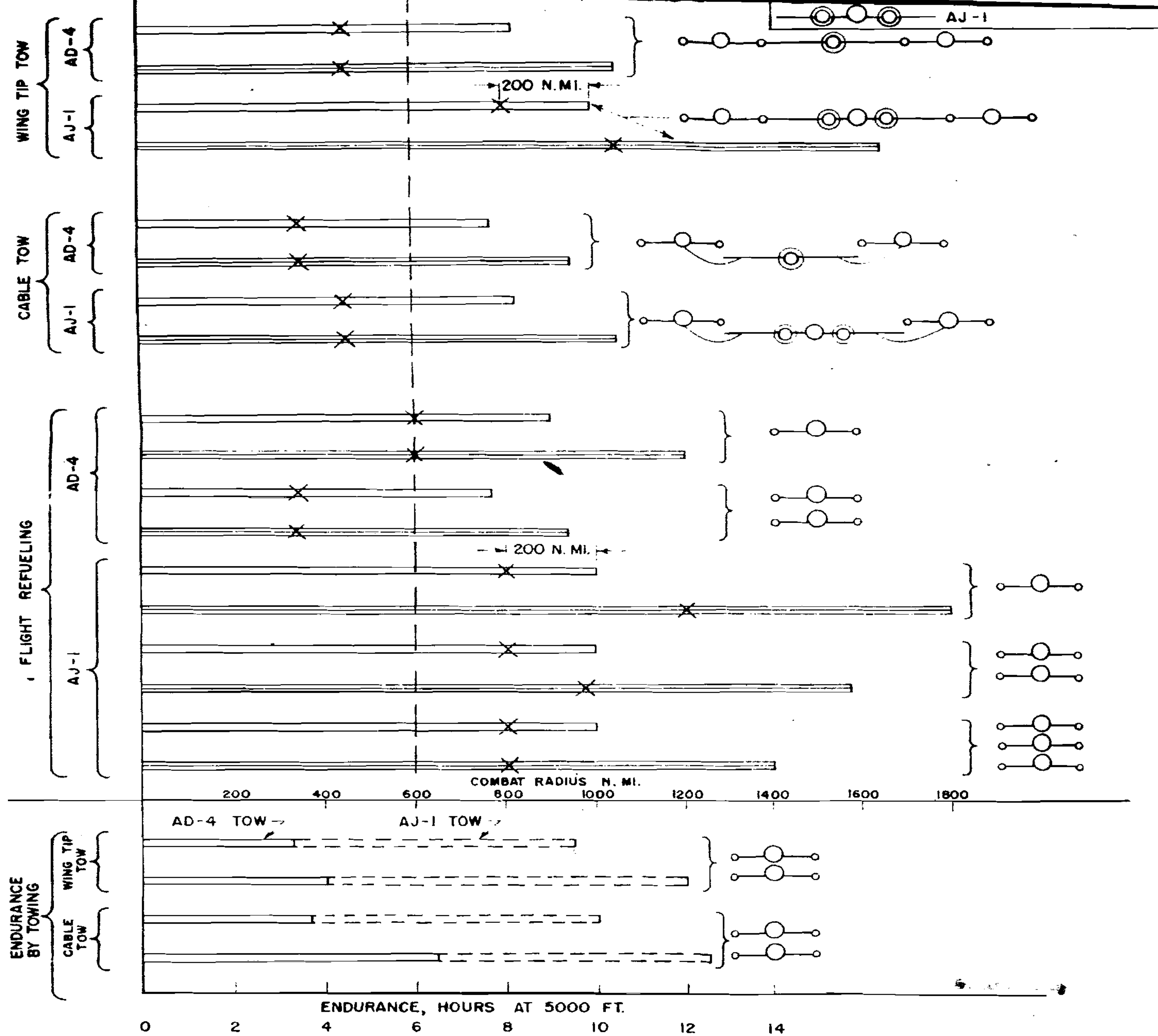
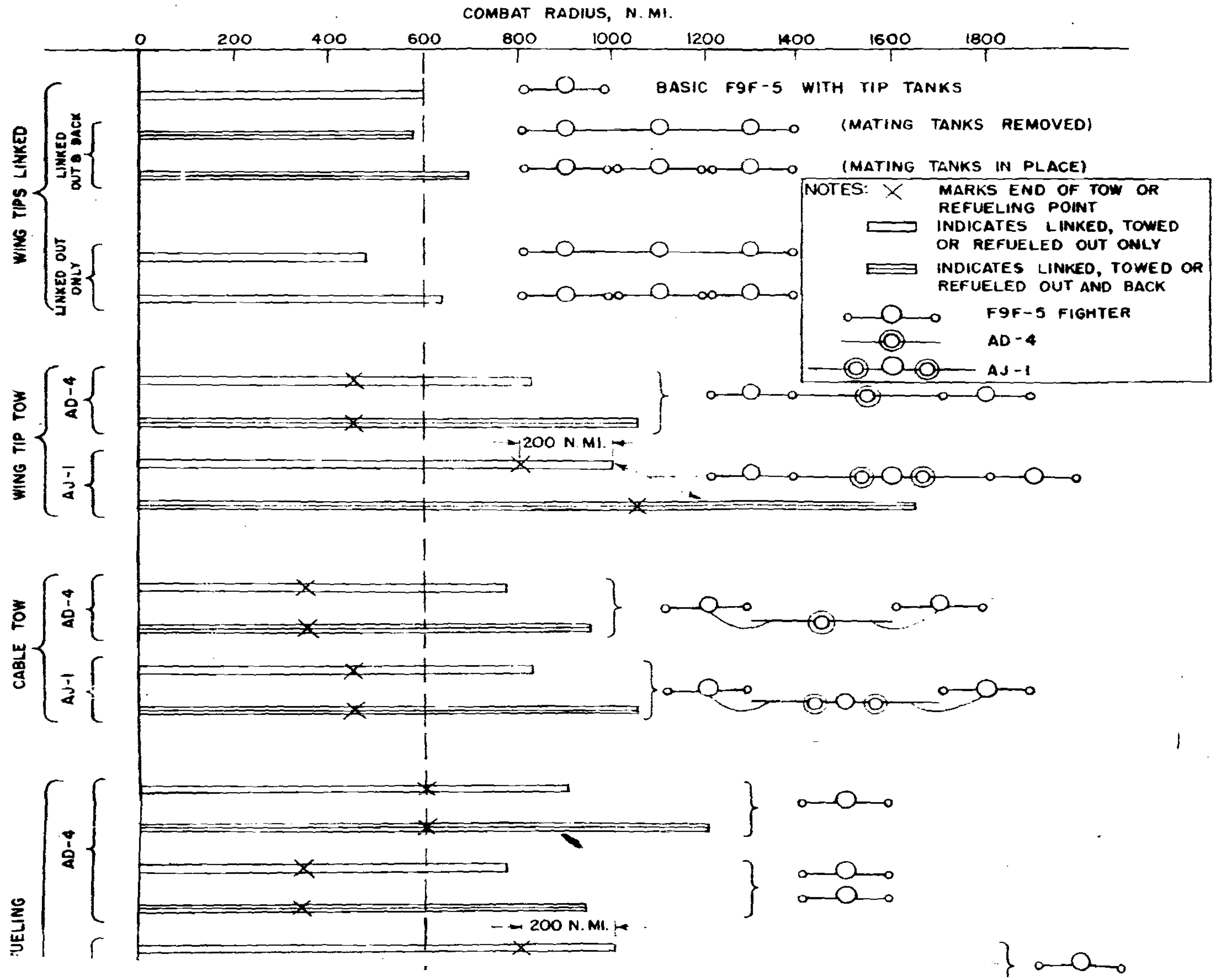
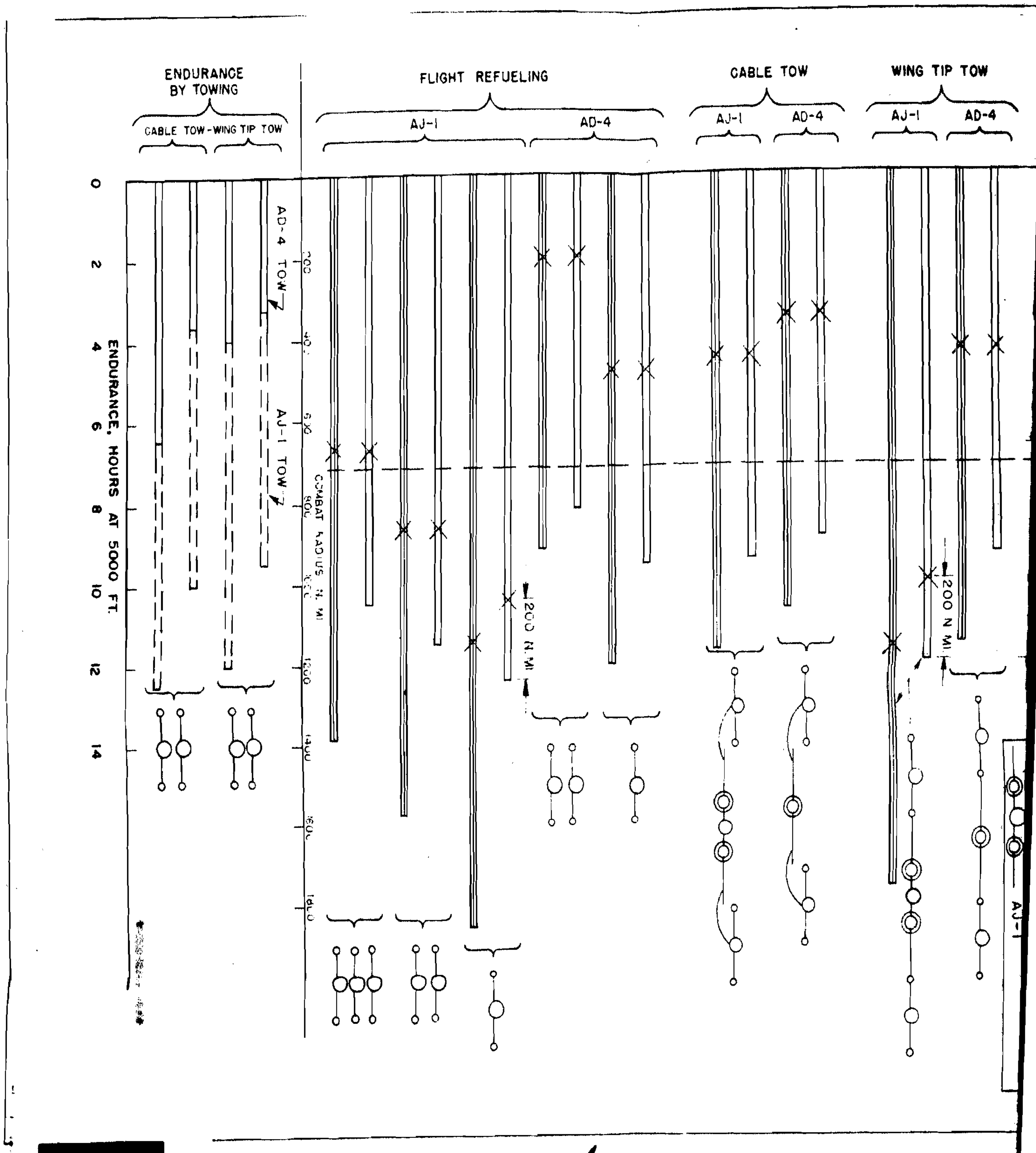


WING TIP TOW
AD-4
AJ-1
CABLE TOW
AD-4
AJ-1
FLIGHT REFUELING
AD-4
AJ-1
200 N. MI.
200 N. MI.
AJ-1
COMBAT RADIUS N. MI.
200
400
600
800
1000
1200
1400
1600
1800
ENDURANCE BY TOWING
WING TIP TOW
CABLE TOW
AD-4 TOW
AJ-1 TOW
ENDURANCE, HOURS AT 5000 FT.
0
2
4
6
8
10
12
14

RANGE AND ENDURANCE EXTENSION F9F-5

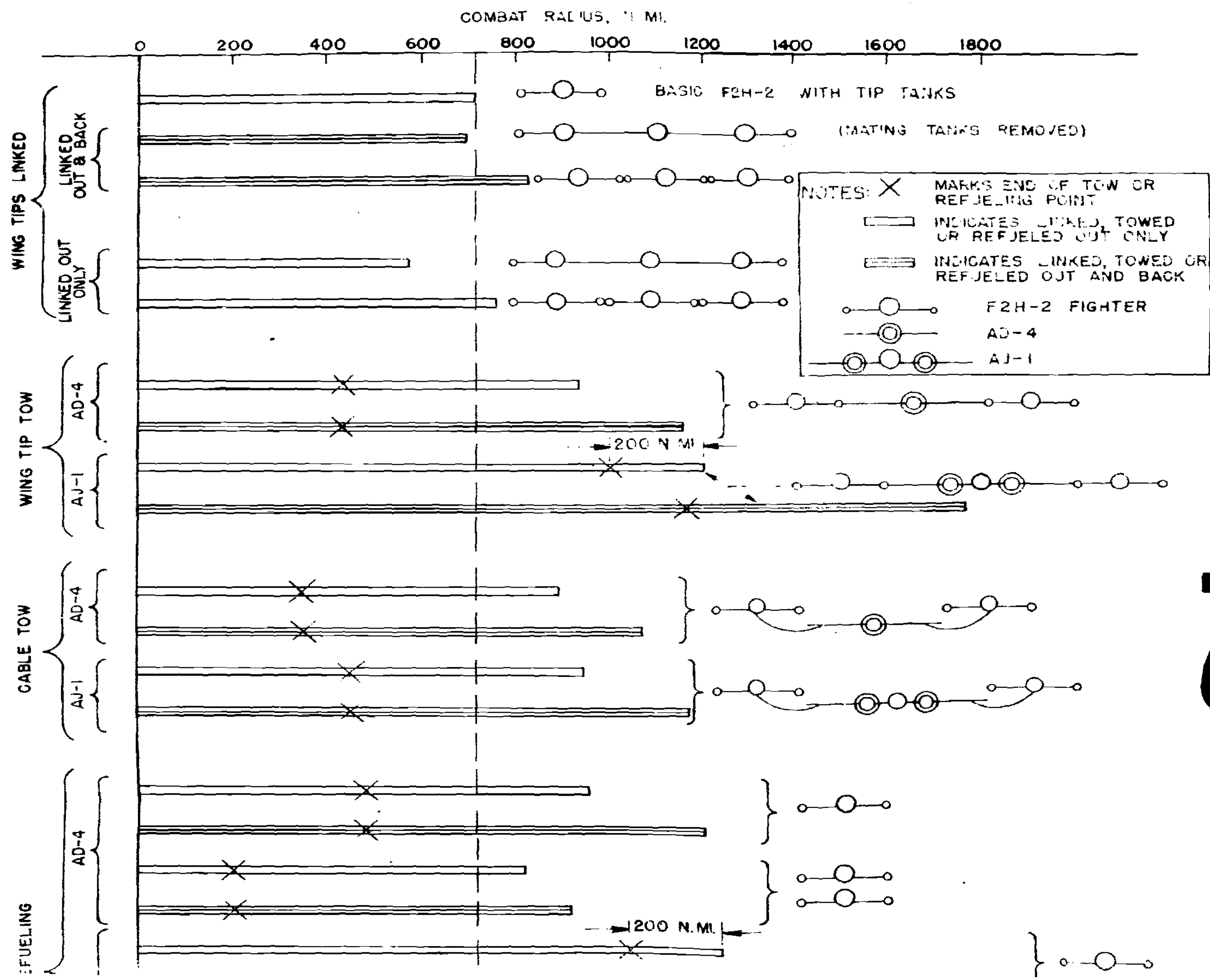
[redacted]




ENDURANCE BY TOWING
CABLE TOW - WING TIP TOW
FLIGHT REFUELING
AJ-1
AD-4
CABLE TOW
AJ-1
AD-4
WING TIP TOW
AJ-1
AD-4
ENDURANCE, HOURS AT 5000 FT.
0
2
4
6
8
10
12
14
AD-4 TOW
AJ-1 TOW
COMBAT RADIUS N. MI
200 N. MI
200 N. MI
AJ-1

RANGE AND ENDURANCE EXTENSION
F2H-2

[redacted]



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show the relative merit.

See Appendix I for flight plans.

The results summarized in figures (1) and (2) are felt to be realizeable upper values which, however, will require the closest attention to weight, aerodynamic cleanliness and operational training.

3. Technical Problems

The technical problems to be encountered are difficult to assess at this time. However, some of the considerations which may apply to each method of range extension are discussed below:

a. With respect to wing-tip linked fighters;

(1) Wing-tip fuel tanks are used on both the F9F-5 and the F2H-2. If they are entirely removed from the airplane the linking of wing-tips result in no improvement and in some cases a sizeable reduction in range or endurance because of the reduced fuel load which can be carried. It appears that some provision in the wing-tip linking system must be made to permit the retention of the wing-tip fuel tanks in order to realize any gains by wing-tip linking. Weight and drag for such provisions have been included in this study.

(2) The advantages which result from this arrangement stem from the increased effective aspect ratio. To realize the range increments shown in this study, it is necessary that aerodynamically smooth and continuous wing joints be provided. Furthermore, the joints should permit the linked aircraft to roll and pitch freely in order

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to minimize the loads imposed on the relatively weak wing-tip structures. Of equally great importance is the ease of engagement and disengagement which the wing-tip joint must provide. Attention to this characteristic will pay dividends in the pilot skill and training required to make satisfactory engagements in unfavorable atmospheric conditions.

(3) Tests reported in reference (a) indicate that the coupled aircraft may have stability characteristics much different from those of the single airplanes. There, in tests involving a transport and a small airplane, it was found that constant attention was required to maintain the position of the small aircraft, it being dynamically unstable in a rolling pitching oscillation; furthermore, the automatic pilot in the small airplane, which was satisfactory for single flight, was unsuited for linked flight. These results are full-scale verification of similar behavior observed in wind tunnel tests of "floating" wing-tips by NACA, reference (b). In the latter test, it was found that the addition of a flap actuated mechanically by the angle between the "floating" wing-tip and the wing of the mother plane could be adjusted to provide stable flight characteristics. From this, it appears that some arrangement acting on the ailerons or elevators of the outboard linked aircraft, either mechanically or through the autopilot, will be required to obtain stable flight of the linked aircraft. However, in considering this problem, it must be recognized that both the Air Force and

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NACA tests involve arrangements where the outboard aircraft or wing surface was small compared to the central unit, and thus, the linking of like aircraft as proposed in this study may present a somewhat different problem, or at least a different degree of severity of the problem.

(4) The effect of linking wing-tips on the weight of the basic wing structure is probably small on aircraft already designed for wing-tip fuel tanks, if freedom to roll and pitch are incorporated in the wing joint. The calculated vertical forces across the linked wing-tips are of the order of 1,000 pounds for the F9F-5, while full wing-tip fuel tanks for that airplane weigh some 750 to 800 pounds each, and are subject to load factors which bring the applied load well above the static loads imposed by linking the wing-tips. However, dynamic loads in the tips may apply loads of sufficiently different nature to require fairly extensive modification of the outboard wing structure. It is felt that actual tests are required to establish this. The degree of modification required locally to accommodate the linking mechanism can only be determined by a program to actually develop a satisfactory linking system. It would appear, however, that packaged tips replacing the present tips of the fighters could be designed to mount on the spar tips and thus minimize modifications to the wings of the fighter, so long as provisions were made for the installation of wing-tip tanks.

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(5) The performance has been calculated on the basis of the engine air intakes on towed aircraft being closed by door while in towed flight.

b. With respect to wing-tip towing of two fighters by reciprocating engined tow planes;

(1) The comments under (3a) above apply with equal force to this operation.

(2) Introduction of unlike airplanes with their associated variations in wing loading one from the other may result in additional complications during rough air operations. For one thing, the response of each airplane to a given gust will be different because of the difference in wing loading, which may generate an erratic flight path and/or excessive loads across the wing-tip junction. These results can only be hypothecated because they do not lend themselves to the analytical approach.

(3) Linking of wing-tips of three or more aircraft results in a distorted spanwise distribution of airload, as described in Appendix II. The effect is to load up the outboard airplane to a higher lift coefficient than that of the combination as a whole. To avoid undesirably high lift coefficients on the outboard airplanes, it is necessary to cruise at a speed somewhat above the theoretical value for maximum range. For example, in the F9F-5; AD-4 combination, a cruising speed of 170 to 180 knots is suitable for the combination where some 150 knots is theoretical maximum range

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speed.

c. Cable towing of two fighters by a reciprocating engine tow plane appears to offer few technical difficulties, at least no more than those encountered in flight refueling by the probe method. In fact, it appears that a suitable towing arrangement using a flight refueling probe as the fighter towing fitting could be worked out. A wing mounting as shown in figure (3) would be a suitable tow point, or perhaps an upper nose location, as shown in figure (4), although the latter offers potential danger to the pilot. In any event, the weight penalty to the towed airplane should be relatively small, and that to the tow plane not unreasonable. It appears that a packaged unit including tow cable, reel, and reel motor could be developed for mounting on external bomb racks of the tow plane. Weight and drag for such units have been included in this study. Forces of 1700 to 2000 pounds are required to tow a 16,000 to 20,000 pound fighter. These forces are well within the designed strength of external bomb racks.

d. Flight refueling techniques have been under development for some time, and the probe system appears to be suitable for fighter refueling. The greatest difficulty in making provision for flight refueling in existing aircraft is the need for back fitting manifolded fueling systems and pressure fueling provisions. Weight penalties of these modifications vary with the fuel systems of aircraft types, but it is felt that 50 to 100 pounds would accommodate the change-over in airplanes of the F9F-5 and F2H-2 type. It appears that flight refueling

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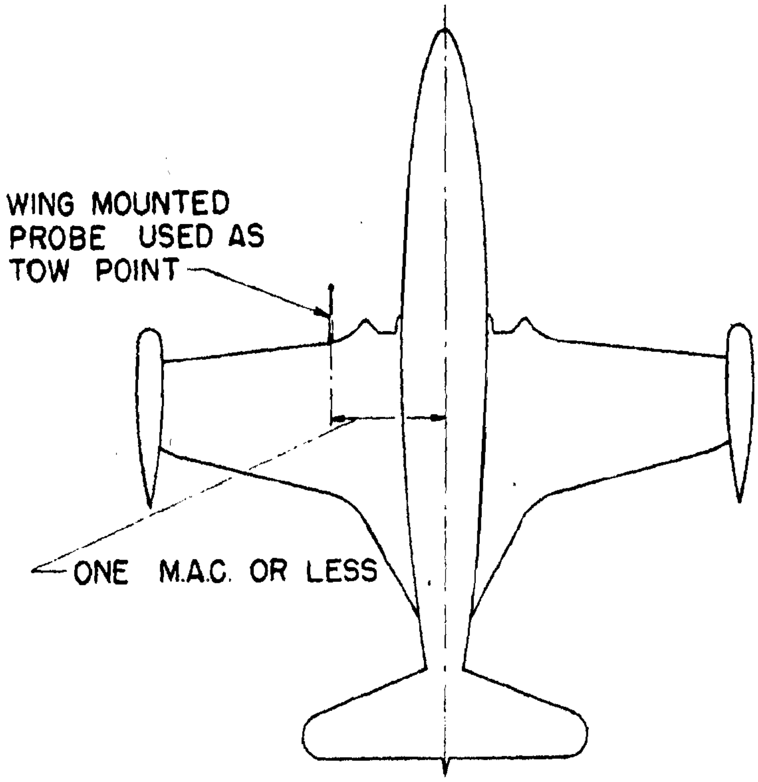
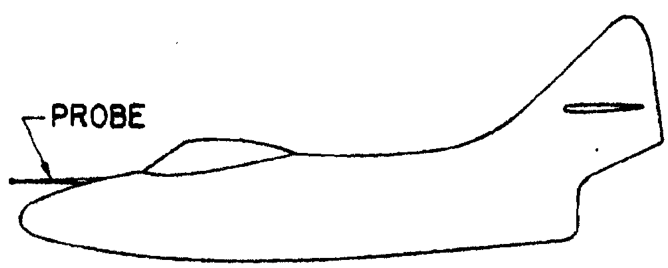


WING LOCATION OF TOWING PROBE
FIG. 3



NOSE LOCATION OF TOWING PROBE
FIG. 4

[redacted]

would result in the same gains and the same problems whether the probe method or some method such as wing-tip transfer were used. The main difference would be that of the equipment required.

4. Operational Problems

All of the methods of range extension considered in this study require that two or more aircraft make physical contact in mid-air. Enough work has been done on flight refueling and towing to indicate that contact can be made successfully. True, the presence of unfavorable atmospheric conditions magnifies the difficulties, but the increase of pilot skill with practice tends to overcome this. Since all methods require contact, no order of merit in this characteristic can be discerned.

However, the location and number of times per mission that contact must be made is important. Assuming that the best method is that requiring the fewest number of contacts at points closest to the take-off point, the order of merit is as follows, listing the most desirable first:

1.	Fighters linked at wing-tips	- out only
	Wing-tip tow	- out only
	Cable tow	- out only
2.	Fighters linked at wing-tips	- out and back
	Wing-tip tow	- out and back
	Cable tow	- out and back
3.	Flight refueling	- out only
4.	Flight refueling	- out and back

Towing and flight refueling, in which one tow plane or tanker serves two

[redacted]

fighters, increases the number of aircraft required to perform the mission by 50%. To the carrier this means a reduced number of strikes which can be launched with a given number of aircraft. Furthermore, when using the AJ-1 as a tanker or tow plane, the number of carriers available for operations is sharply reduced over that of fighters acting singly.

C O N F I D E N T I A L

REFERENCES

1. AMC Flight Test Div. Conf Report No. MCRFT-2283, dtd 20 April 1950, "Pilot's Comments on Wing-Tip Coupling of Aircraft."

2. NACA Conf. Research Memorandum, "Flight Tests of a Model having Self-Supporting Fuel-Carrying Panels Hinged to the Wing Tips," RM No. L9I07a, dtd Nov 2, 1949.

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APPENDIX I

ASSUMED FLIGHT PLANS

1. Tow planes carry 20% of their initial fuel load all the way as allowance for warmup, take-off, climb, and reserve.

2. Refueling planes carry 20% of their initial fuel load all the way as allowance for warmup, take-off, climb, and reserve; 15 minute delay allowance at maximum endurance speed for rendesvous.

3. Fighters fly F-5 problem after leaving assisting airplanes, except that tip tanks are retained through combat where fuel remains in them at combat. In flight refueling, fighters fly out to refueling point in accordance with outbound portions of F-5 problem.

4. All fuel consumptions increased 5%.

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APPENDIX II

SOME EFFECTS OF LINKING WING TIPS

The simple concept of the aerodynamic effects of wing-tip linking is that the increase in span has a favorable effect upon induced drag. Indeed, the effect of linking together any number of like aircraft should theoretically permit all to be flown for the <u>induced</u> drag of only one airplane. For cruising flight where the speed for maximum range is close to that for maximum lift-drag ratio, i.e., reciprocating engined aircraft at any altitude, and gas turbine engined aircraft at high altitudes, this would result in a very handsome gain in range or endurance.

Upon closer examination, however, the situation becomes more complex. Consider the case of two aircraft linked at the wing-tips, as sketched in figure 1. In order to realize the benefits of wing-tip linking, it is necessary to create a span distribution carrying across the wing tip junction. Figure 2 indicates how the spanwise location of the center of lift on each airplane of the team is thus displaced from the center of gravity of that airplane. This displacement sets up a significant unbalanced moment which must be transmitted across the wing tip juncture. Because of structural and possible stability difficulties, it is considered more feasible to provide a hinged joint at the wing tip, which therefore can transmit no moment. Under these circumstances the desirable loading must be destroyed by use of ailerons to a degree sufficient to reduce the moment at the linked tips to zero. Calculations of a span distribution that does this, figure 3, indicate that most, if not all, of the beneficial effects of linking on the induced drag are

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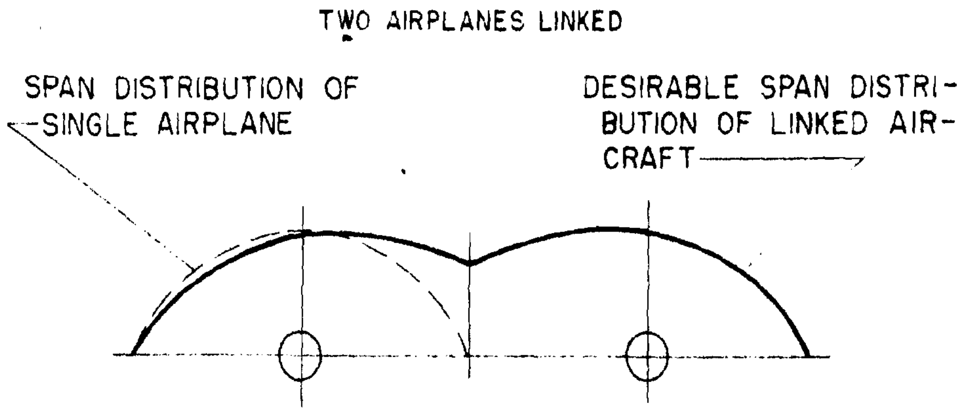

FIGURE 1

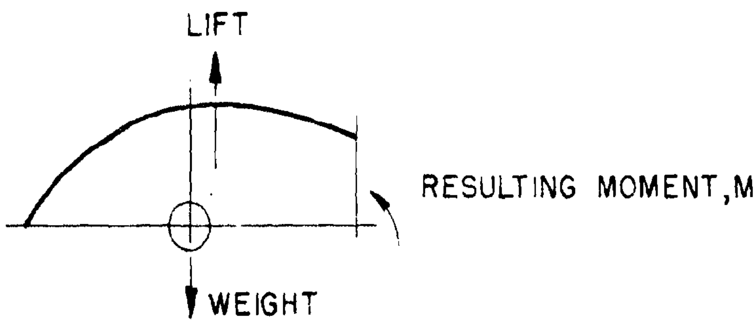

FIGURE 2

VERTICAL FORCES ON SINGLE AIRPLANE
OF TWO–AIRPLANE–LINKED ARRANGEMENT
—AILERON NEUTRAL

[redacted]

destroyed and additional parasite drag is introduced by the aileron deflections required to trim. Preliminary results of brief wind tunnel tests conducted by the David Taylor Model Basin indicate that the calculations are correct in order of magnitude.

Linking of more than two aircraft, say, three for example, permits a different solution. While the unbalanced rolling moment problem still exists, it can be corrected by the elevators of the outboard aircraft rather than by aileron. As shown in figure (4), the generation of additional lift on the outboard airplanes, with depressed lift on the center airplane, creates a moment corrective in sign. Calculations of the effect of the mutilated span loading resulting from this type of flight indicate that the penalties on theoretical induced drag are substantial, but that noticeable gains in range or endurance can be realized, by towing with reciprocating engined aircraft.

To summarize, it is felt that linking of two aircraft wing-tip to wing-tip will provide essentially no change in the drag characteristics of the individual aircraft. However, linking of three or more aircraft should be beneficial to the range and endurance, but to a lesser degree than simple theory would indicate.

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EFFECT OF USE OF AILERONS TO REDUCE M TO ZERO
TWO AIRPLANES LINKED

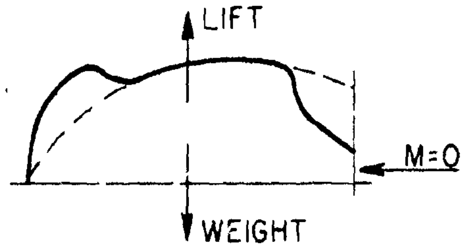

FIGURE 3

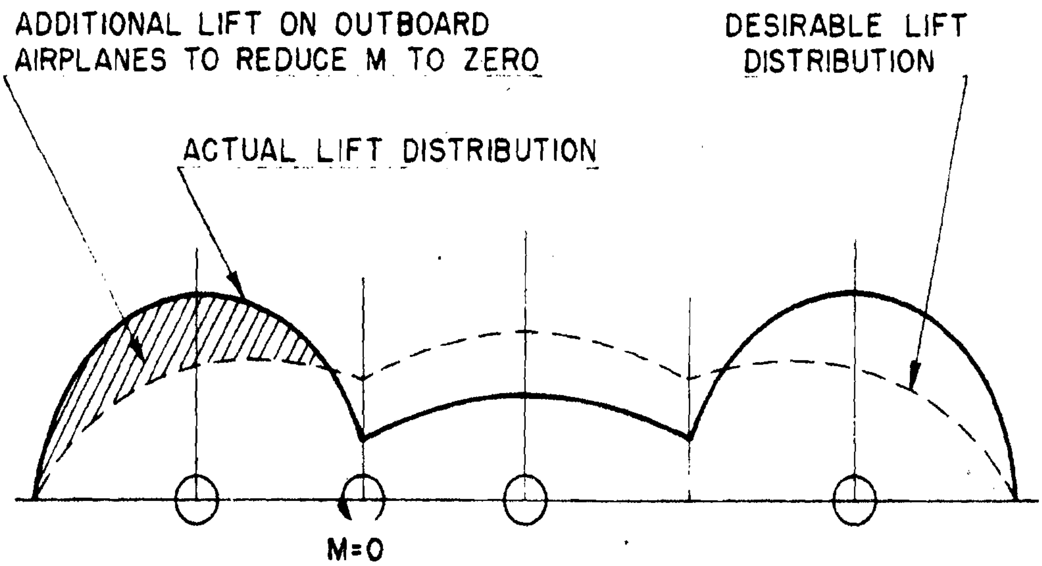

FIGURE 4
THREE AIRPLANES LINKED

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