

## NRC Publications Archive Archives des publications du CNRC

**Performance study of 1962 tilt-wing V.T.O.L. medium-sized transport aircraft: comparison of tip jet and conventional turboprop powerplants**  
Cockshutt, E. Philip; Fowler, Howard S.

For the publisher's version, please access the DOI link below./ Pour consulter la version de l'éditeur, utilisez le lien DOI ci-dessous.

### **Publisher's version / Version de l'éditeur:**

<https://doi.org/10.4224/40003865>

*Laboratory Memorandum (National Research Council Canada. National Aeronautical Establishment. Engine Laboratory); no. NAE-ENG-52, 1957-06-10*

### **NRC Publications Archive Record / Notice des Archives des publications du CNRC :**

<https://nrc-publications.canada.ca/eng/view/object/?id=6872e2a3-a34f-45d9-9bd6-1a79b354ac67>

<https://publications-cnrc.canada.ca/fra/voir/objet/?id=6872e2a3-a34f-45d9-9bd6-1a79b354ac67>

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at

<https://nrc-publications.canada.ca/eng/copyright>

READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site

<https://publications-cnrc.canada.ca/fra/droits>

LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

**Questions?** Contact the NRC Publications Archive team at

PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

**Vous avez des questions?** Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.

L.O. **NAE-446-1**

FILE **CM2-17-13T-6**

**E.P.C.**

PREPARED BY **H.S.F.**

CHECKED BY

NATIONAL AERONAUTICAL ESTABLISHMENT  
OTTAWA, CANADA \*

LABORATORY MEMORANDUM

SECTION **ENGINE LABORATORY**

NO. **NAE-ENG-52**

PAGE **1** OF **11**

COPY NO. **20**

DATE **10 June, 1957**

SECURITY CLASSIFICATION **Confidential**

DECLASSIFIED  
DÉCLASSIFIÉ

SUBJECT

**Performance Study of 1962 Tilt-Wing  
V.T.O.L. Medium-Sized Transport Air-  
craft: Comparison of Tipjet and  
Conventional Turboprop Powerplants.**

PREPARED BY

**E. Philip Cockshutt and Howard S. Fowler**

ISSUED TO

**Internal**

THIS MEMORANDUM IS ISSUED TO FURNISH INFORMATION  
IN ADVANCE OF A REPORT. IT IS PRELIMINARY IN CHARACTER,  
HAS NOT RECEIVED THE CAREFUL EDITING OF A REPORT, AND  
IS SUBJECT TO REVIEW.

## LABORATORY MEMORANDUM

SUMMARY.

The all-up weights of tilt-wing V.T.O.L. aircraft using tipjets to drive the propellers are presented for the following mission:

Payload	5,000 lb.
Range	500 miles
Hovering Duration	10 minutes
Cruising Altitude	10,000 ft.
Wing Loading	60 lb/ft <sup>2</sup> .

The independent variables investigated are propeller disc loading, propeller tip speed, and aircraft cruising speed; an engine of the mixed-bypass type is assumed as the gas generator.

It is shown that only for propeller tip speeds of the order of 900 ft/sec. does the tipjet configuration produce aircraft weights as low as those with a conventional turboprop configuration. The gas ducting used to pneumatically interconnect the engines appears to have about the same weight as the mechanical shafting used with the turboprops. Even with tip speeds of the order of 900 ft/sec, the tipjet has a high fuel consumption, but the low powerplant weight makes it competitive with the turboprop configuration.

TABLE OF CONTENTS

	Summary.
	List of Illustrations.
1.0	Introduction.
2.0	Description of Proposed Installation.
3.0	Calculation Procedure.
	3.1 Scope of Investigation.
	3.2 Working Formulae.
4.0	Calculated Weights.
5.0	Discussion of Results.
6.0	Conclusions.

LIST OF ILLUSTRATIONS

1. General Layout.
2. Ducting Diagram.
3. Engine Installation.
4. Calculated All-up Weight -  $\omega = 30$ .
5. Calculated All-up Weight -  $\omega = 40$ .
6. Calculated All-up Weight -  $\omega = 70$ .
7. Weight Breakdown - Tipjet Configuration.
8. Weight Breakdown - Turboprop Configuration.

PERFORMANCE STUDY OF 1962 TILT-WING V.T.O.L.  
MEDIUM-SIZED TRANSPORT AIRCRAFT: COMPARISON OF  
TIPJET AND CONVENTIONAL POWERPLANTS

---

Introduction:

In two memoranda prepared by the Aerodynamics Section (AE-85 and AE-85A), calculated gross weights were presented for aircraft capable of performing a prescribed V.T.O.L. mission. These aircraft were assumed to be powered by turboprop engines appropriate to 1962, and the following parameters were investigated: propeller disc loading, propeller tip speed, design cruising altitude, design cruising speed, and wing loading. The results of these studies have been selected as a datum to which other and, perhaps less conventional, configurations may be referred; it is the purpose of this memorandum to investigate the effects of replacing the turboprop engines with mixed-bypass turbojets driving propellers through tipjets.

2.0 Description of Proposed Installation.

Four bypass turbojets are mounted in the tilting wings in the same positions as the turboprop engines of AE-85, but they are mounted back-to-front. Cascaded 180° bends in the air-intakes below the wing give almost full ram pressure recovery. The "jet pipes" of the engines extend forward as stiff pillars and act as the propeller-shaft mountings. On these four hubs are the propellers, driven by the 450°C engine exhaust gas issuing from jets at the tips of their hollow blades. Figure 1 is a general sketch of the proposed layout.

In order to ensure safety in case of one-engine failure, an interconnecting gas duct system is fitted. A stack from each "propeller-shaft" duct comes back to a common duct buried in the wing. This duct is always open to all engines, but no flow takes place in it except in case of engine failure. The ducting is designed on jet pipe practise, with a light shroud and

cont'd...

small annular airspace. Sufficient airflow is allowed in the gap to cool the outer shroud to a safe temperature without removing more heat from the exhaust-gas than necessary. Expansion joints of the metal bellows type are fitted. The duct system is shown in Figure 2. The only valve gear needed is shown in Figure 3. Non-return valves of a simple nature are fitted at the exit from each engine, to prevent much loss of gas through it when failed or shut down for cruising, and restrictors, never requiring to close the duct completely, are fitted in each propeller inlet, to divert some of the gas through the ducting to supply the propeller of a failed engine.

The system has been considered to this extent in order to enable the weights to be estimated for comparison with the interconnecting shafting and gearbox weights of the AE-85 proposal. It is considered that the manufacture and maintenance of the duct system would be considerably cheaper than that of a shaft and gearbox system, regardless of the weight effects.

### 3.0 Calculation Procedure.

#### 3.1 Scope of Investigation.

As in the previous studies, the basic requirements of the aircraft mission were as follows:

Payload	5,000 lb.
Range	500 miles
Hovering Duration	10 minutes
Hovering Capability	6,000 ft. altitude at 95°F.

In order to simplify the investigation, and after consultation with the authors of AE-85 and AE-85A, the mission has been further restricted for this study as follows:

Cruising Altitude	10,000 ft.
Wing Loading	60 lb/ft <sup>2</sup> .

The parameters investigated herein, and the values used, are listed below:

cont'd...

## LABORATORY MEMORANDUM

Propeller Disc Loading,  $\omega$ , 30, 40, 70 (lb/ft<sup>2</sup>)  
 Propeller Tip Speed,  $V_t$ , 500, 600, 700, 800, 900 (ft/sec.)  
 Design Cruising Speed,  $V$ , 200, 300, 400 (mph).

3.2 Working Formulae.

As in AE-85A, the aircraft gross weights were calculated from the following relation:

$$W = \frac{P + W_{fb}}{1 - \sum r}$$

Where  $W$  = Gross weight.  
 $P$  = Payload.  
 $W_{fb}$  = Cruising fuel (body).  
 $r$  = Weight fraction.

The relations for the various weight fractions,  $r$ , are listed below and except as noted have been taken from memorandum AE-85:

- (a) Miscellaneous (undercarriage, controls, empennage):  $r_m = 0.116$
- (b) Body:  $r_f = 0.088$
- (c) Wings:  $r_w = 0.0588 + \frac{9.81}{\omega 1.5}$
- (d) Propellers:  $r_p = \frac{41}{\sqrt{\Lambda} V_t^2 \omega 1.5} 0.31$

Where  $\Lambda$ , the disc power loading in lbs/HP, is tabulated as a function of  $\omega$  and  $V_t$  in AE-85.

- (e) Ducting:  $r_d = \frac{3.21}{\sqrt{\beta} \Lambda \omega}$

This item replaces the mechanical interconnection items of AE-85 (synchronizing transmission, synchronizing shafting, and propeller extension shafts), and includes the complete ducting system described above.

cont'd...

## LABORATORY MEMORANDUM

$\beta$  is the specific power of the combined powerplant - tipjet system, and is computed from:

$$\beta = \frac{v_t^2 \left( \sqrt{\left(\frac{v_j}{v_t}\right)^2 + 1} - 1 \right)}{550 \xi}$$

$v_j$  is a function of the engine cycle assumed and represents the jet velocity which the mixed-bypass engine would produce when acting as a conventional turbojet. The value of  $v_j$  used herein was 1700 ft/sec., and corresponds to the unheated mixed-bypass cycle described in Engine Laboratory Memorandum NAE-ENG-48.

(f) Powerplant:

$$r_{pp} = \frac{34.6}{\beta \lambda}$$

This relation was derived assuming an installed engine weight of 23 lbs/lb/sec. of airflow for the bypass engine, as compared with 65 lbs/lb/sec. as assumed for the turboprop.

(g) Hovering fuel:

$$r_h = \frac{.210\alpha}{\lambda}$$

$\alpha$  is the design specific fuel consumption, and is computed from:

$$\alpha = \frac{39.8}{\beta}$$

(h) Climbing fuel:

$$r_{cl} = 0.005$$

This value was chosen as an average value using Figure 16 of AE-85A.

(i) Cruising fuel consumption (except body):

$$r_{cr} = 1.39\alpha \left[ 0.0049 \left(\frac{V}{100}\right)^2 + \frac{.0028 \omega}{\left(\frac{V}{100}\right)^2} \right]$$

cont 'd...

The following items were also extracted from AE-85A:

$$P = 6100$$

$$W_{fB} = 218a \left( \frac{V}{100} \right)^2$$

#### 4.0 Calculated Weights.

The results of following the calculation procedure outlined above are summarized in Figures 4, 5 and 6, which have been drawn for propeller disc loadings of 30, 40 and 70 lb/ft<sup>2</sup> respectively. In each case the abscissa is the design cruising speed for the aircraft and the ordinate is the gross or all-up weight of the aircraft.

Curves for tip speeds of 500, 600 and 700 ft/sec. have been drawn with solid lines, and use the power loading data of memoranda AE-85 and AE-85A.

It was soon apparent, however, that any successful tip-jet scheme would require propeller tip speeds higher than 700 ft/sec., and that the propeller assumed in the foregoing studies was unsuitable. It was, therefore, assumed that the same lifting efficiency (as indicated by power loading) tabulated for 600 ft/sec. could be obtained, after some development, at tip speeds of 800 and 900 ft/sec; this appears reasonable for NACA 16 blade sections, as is discussed in NAE-ENG-44. To call attention to this assumption, the curves for 800 and 900 ft/sec. have been drawn with broken curves. In addition, the performance of the conventional turboprop configuration is shown on each figure for the optimum tip speed only (600 ft/sec.) with a dashed curve.

Several observations stand out immediately on inspection of these 3 figures. The first is the extreme sensitivity of all-up weight to propeller tip speed for this tipjet drive: by increasing the tip speed from 500 to 900 ft/sec., the all-up weight is approximately halved. The second observation is that only the highest tip speeds (800 and 900 ft/sec.) produce weights which are competitive with those for the conventional turboprop configuration. The third observation is that the aircraft weight

cont'd...

rises rapidly with the design cruising speed of the aircraft, particularly above 300 mph. Finally, by comparing values for different disc loadings on the 3 figures, it is seen that values of 30 and 40 lb/ft<sup>2</sup> produce about the same all-up weights, while 70 lb/ft<sup>2</sup> produces appreciably higher weights.

### 5.0 Discussion of Results.

In order to examine the differences between the tip-jet and turboprop configurations, weight breakdowns (Figures 7 and 8) have been constructed for both configurations for the same design condition (disc loading of 40 lb/ft<sup>2</sup>, and cruising speed of 300 mph), with tip speed as the independent variable. In both cases, the structure weight (wings, body and miscellaneous items) makes up just over 30% of the all-up weight, and the propellers account for another 10%. It is seen that the ducting weight for the tipjet scheme is just about equal to the mechanical interconnect items (propeller extension shafting, synchronizing shafting and synchronizing transmission) for the turboprop scheme, and that each amounts to about 4% of the all-up weight. The installed powerplant weight is a strong function of tip speed with the tipjet drive, decreasing from 25% at 500 ft/sec. to 17% at 900 ft/sec.; with the turboprop configuration the optimum powerplant weight is 21% of the all-up weight. Both hovering and cruising fuel consumptions decrease slightly with tip speed when using tipjets, so that the total fuel consumption decreases from 19% at 500 ft/sec. to 17% at 900 ft/sec.; with the turboprop configuration, however, the total fuel consumption is of the order of 12%.

If one compares the optimum tipjet configuration (900 ft/sec.) with the optimum turboprop configuration (600 ft/sec.), it is seen that the portion of all-up weight available for the fixed load is 26% in each case. The tipjet achieves this with a relatively low powerplant weight and high fuel consumption, while the turboprop has a higher powerplant weight and lower fuel consumption; for this reason the tipjet scheme should show an advantage on missions shorter than the assumed 500 mile range.

cont'd...

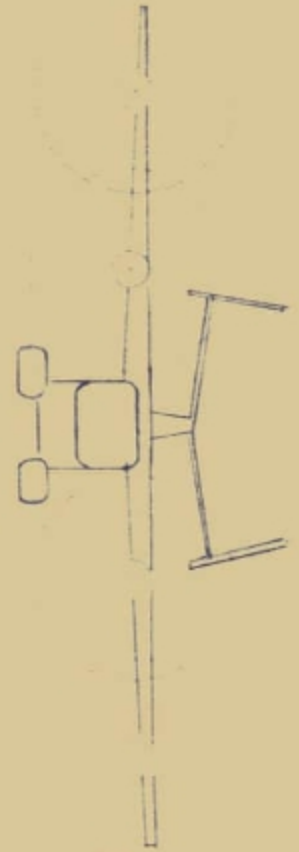
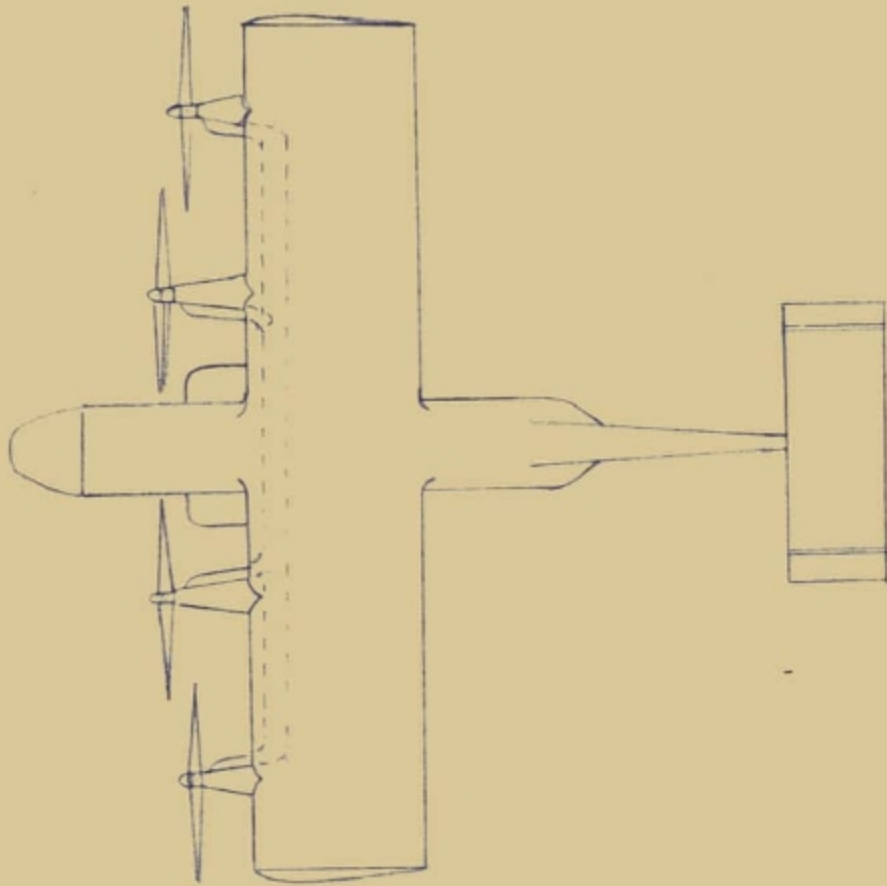
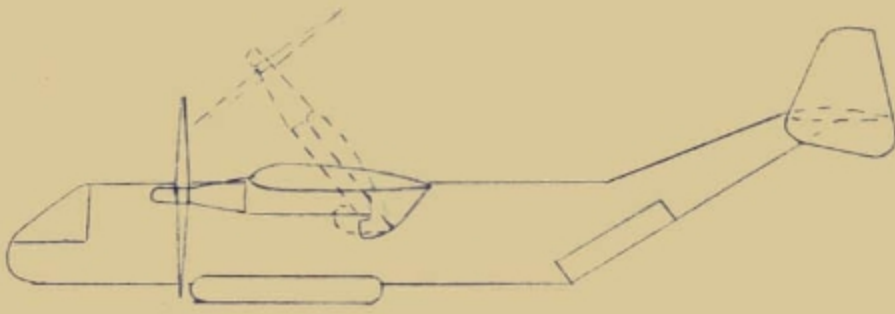
## LABORATORY MEMORANDUM

## 6.0 Conclusions.

1. If a tipjet scheme is to produce aircraft all-up weights comparable with those of a turboprop configuration, propellers maintaining good efficiency at tip speeds of about 900 ft/sec. will be required.

2. The weight of interconnecting ducting with a tipjet scheme appears to be very similar to the weight of interconnecting shafting with a turboprop scheme.

3. Tipjet schemes appear to imply higher fuel consumption but lower powerplant weight than turboprop schemes.



GENERAL LAYOUT —

TIP-JET PROPELLER-DRIVEN VTOL AIRCRAFT

PROPOSAL

FIG. 1.

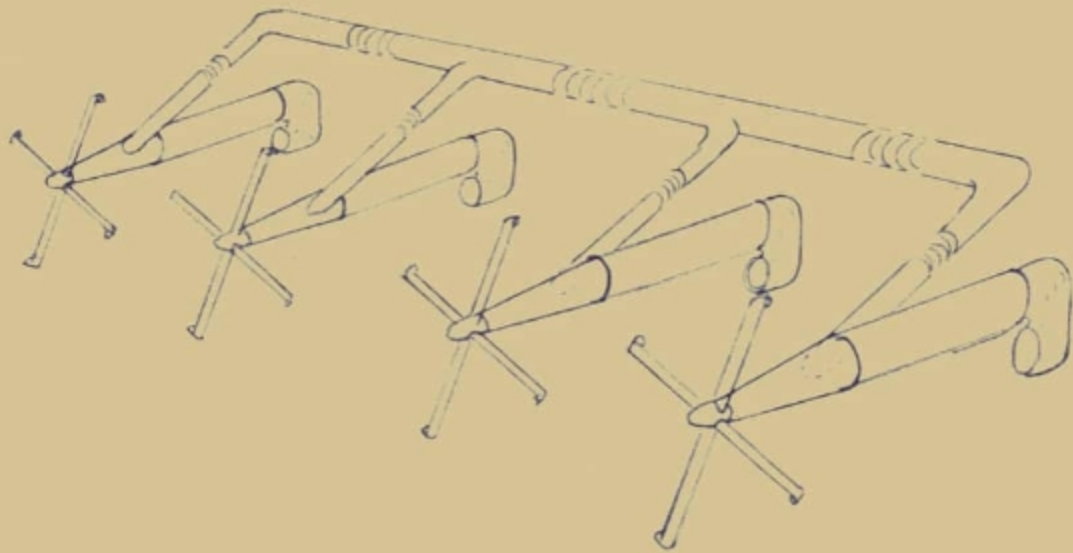


FIG. 2.

DUCTING DIAGRAM -  
TIP-JET PROPELLER-DRIVEN VTOL AIRCRAFT PROPOSAL

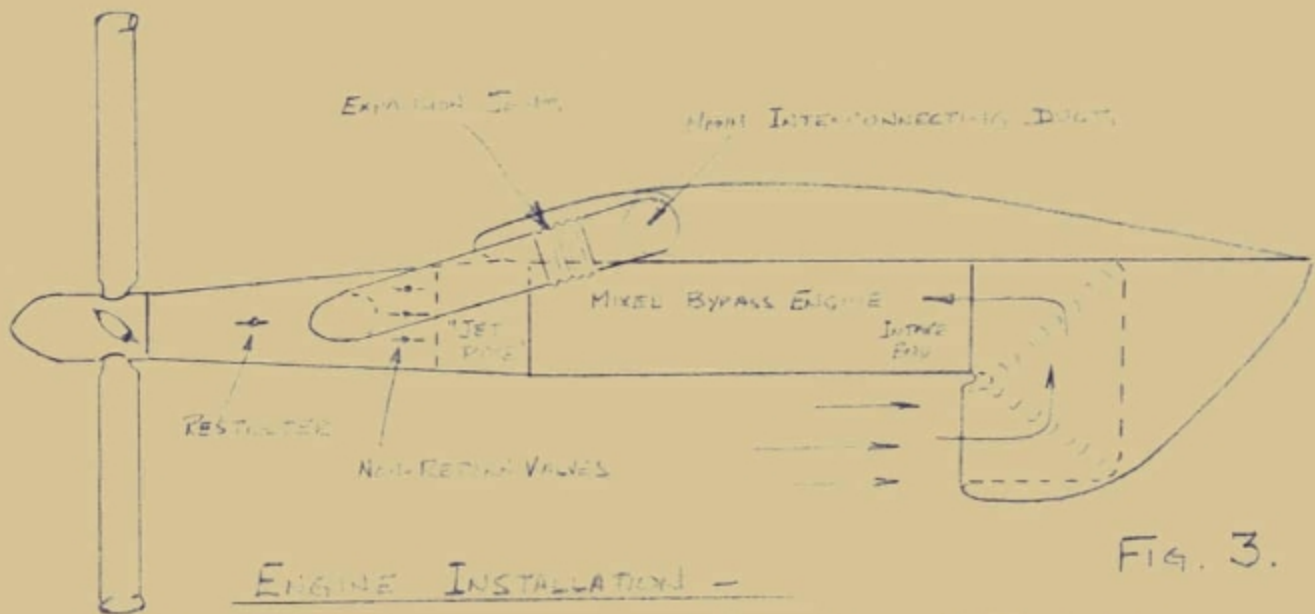


FIG. 3.

ENGINE INSTALLATION -  
TIP-JET PROPELLER-DRIVEN VTOL AIRCRAFT PROPOSAL -

# CALCULATED ALL-UP WEIGHT

Disc Loading  $\sigma = 30 \text{ lb/ft}^2$

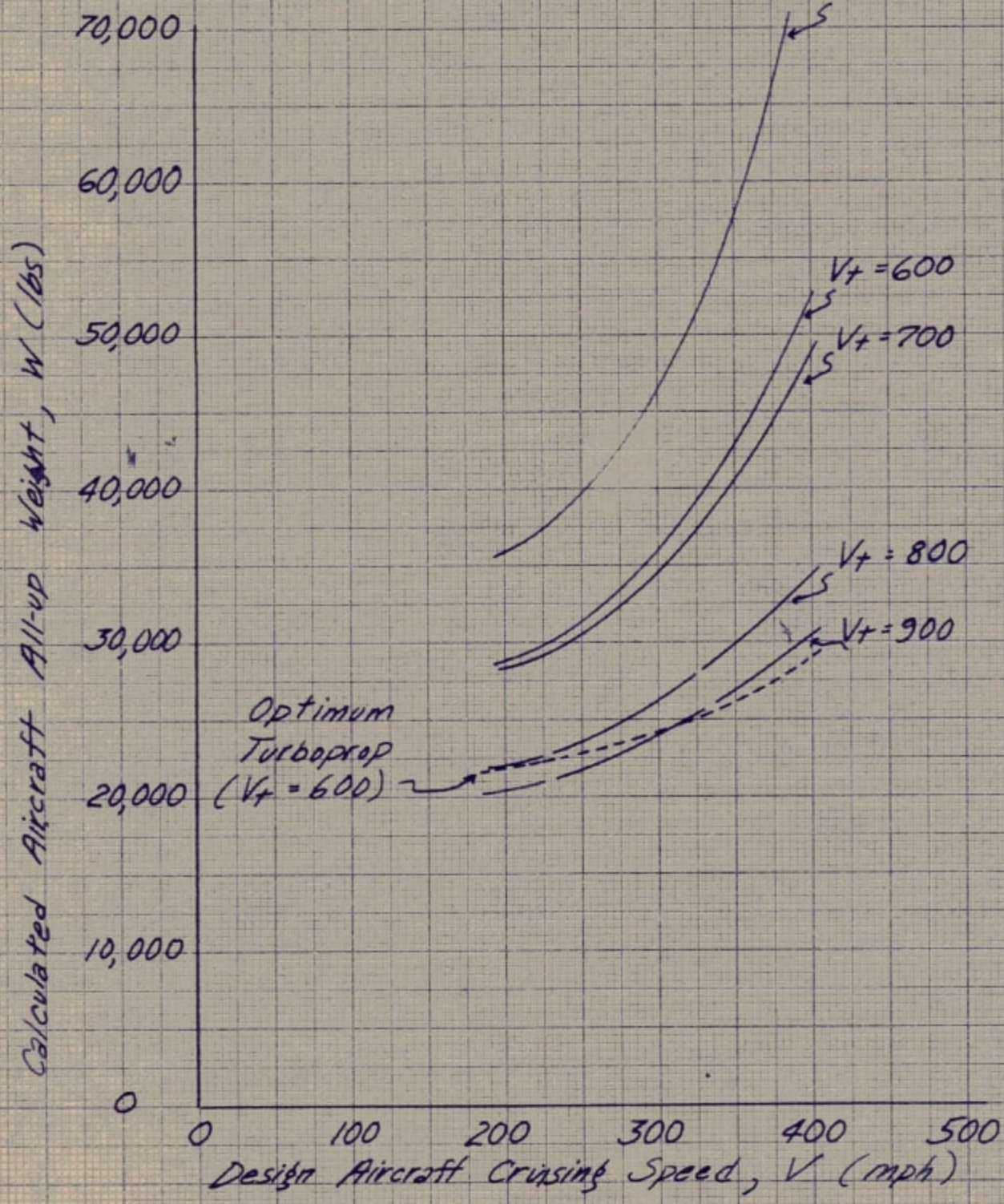
Alt = 10,000 ft

Range = 500 mi

W/S = 60 lb/ft<sup>2</sup>

Tipjet Tip Speeds

$V_t = 500 \text{ ft/sec}$



K&E KENNEL & ESSER CO. MADE IN U.S.A. 10 X 10 TO THE 1/2 INCH 328-15

Fig. 5

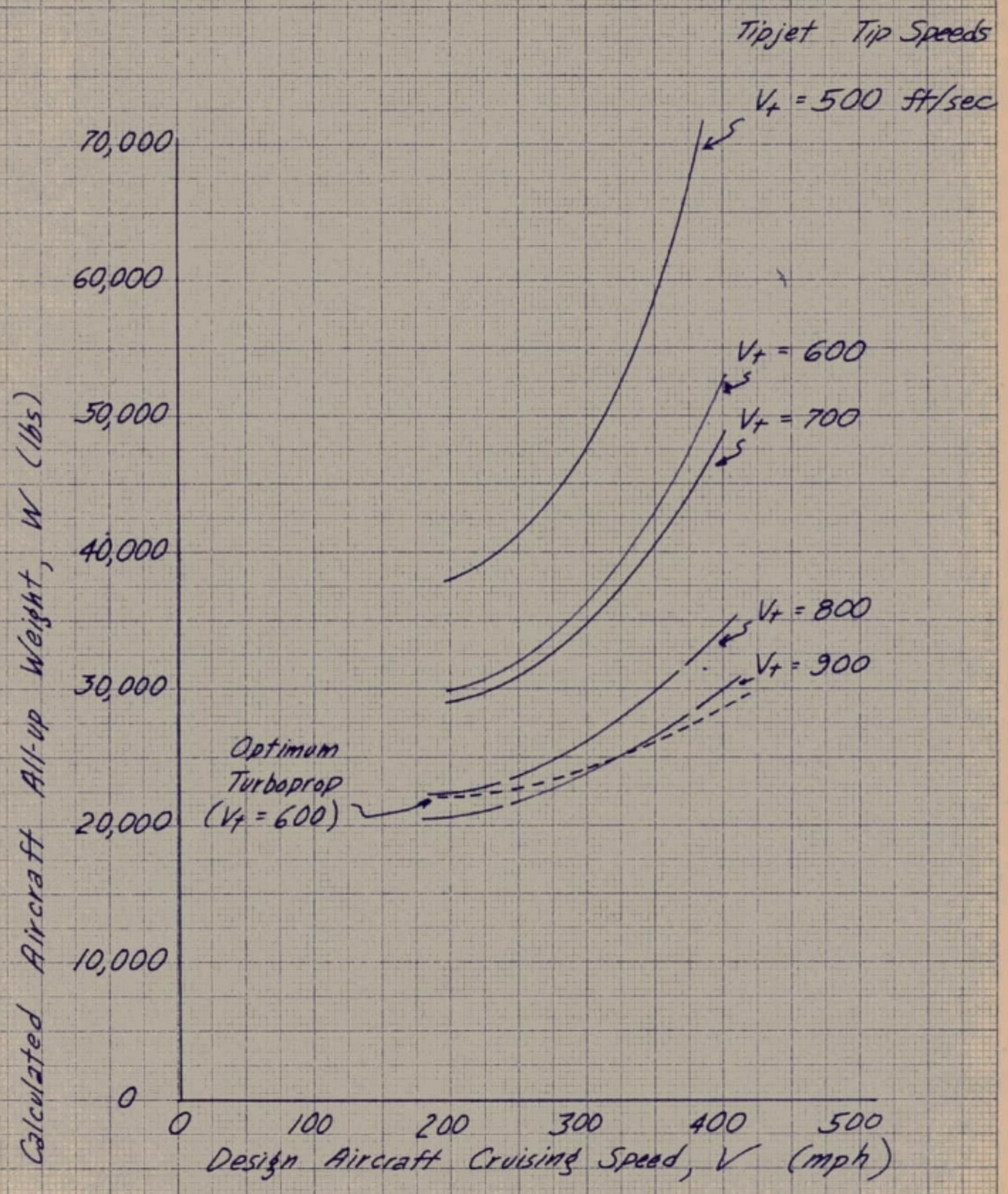
# CALCULATED ALL-UP WEIGHT

Disc Loading,  $\bar{w} = 40 \text{ lb/ft}^2$

Alt = 10,000 ft

Range = 500 mi

W/S = 60 lb/ft<sup>2</sup>

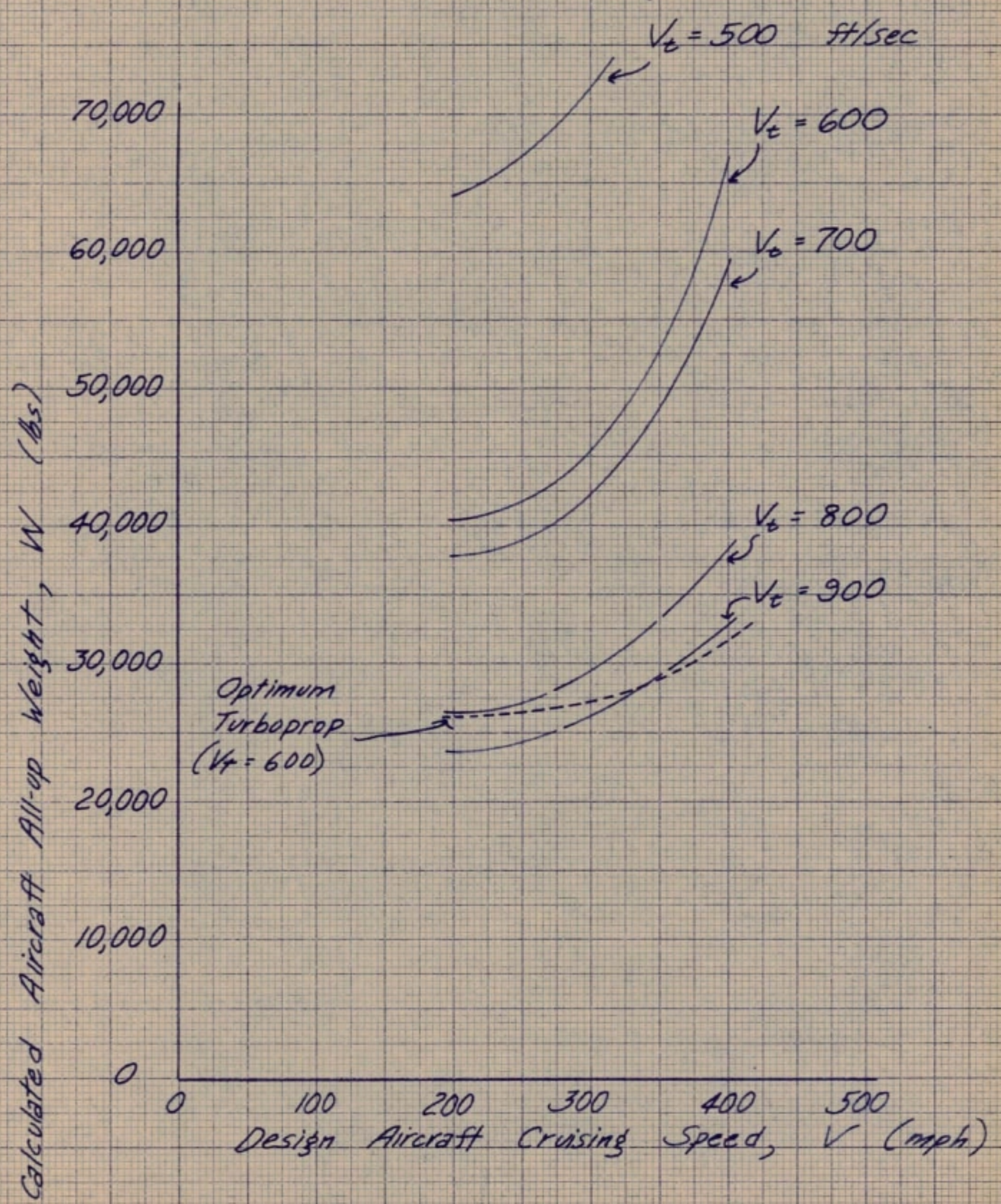


K&E KODAK SAFETY FILM 10 X 10 TO THE INCH MADE IN U.S.A. 329-15

# CALCULATED ALL-UP WEIGHT

Disc Loading = 70 lb/ft<sup>2</sup>  
 Alt = 10,000 ft      Range = 500 mi      W/S = 60 lb/ft<sup>2</sup>

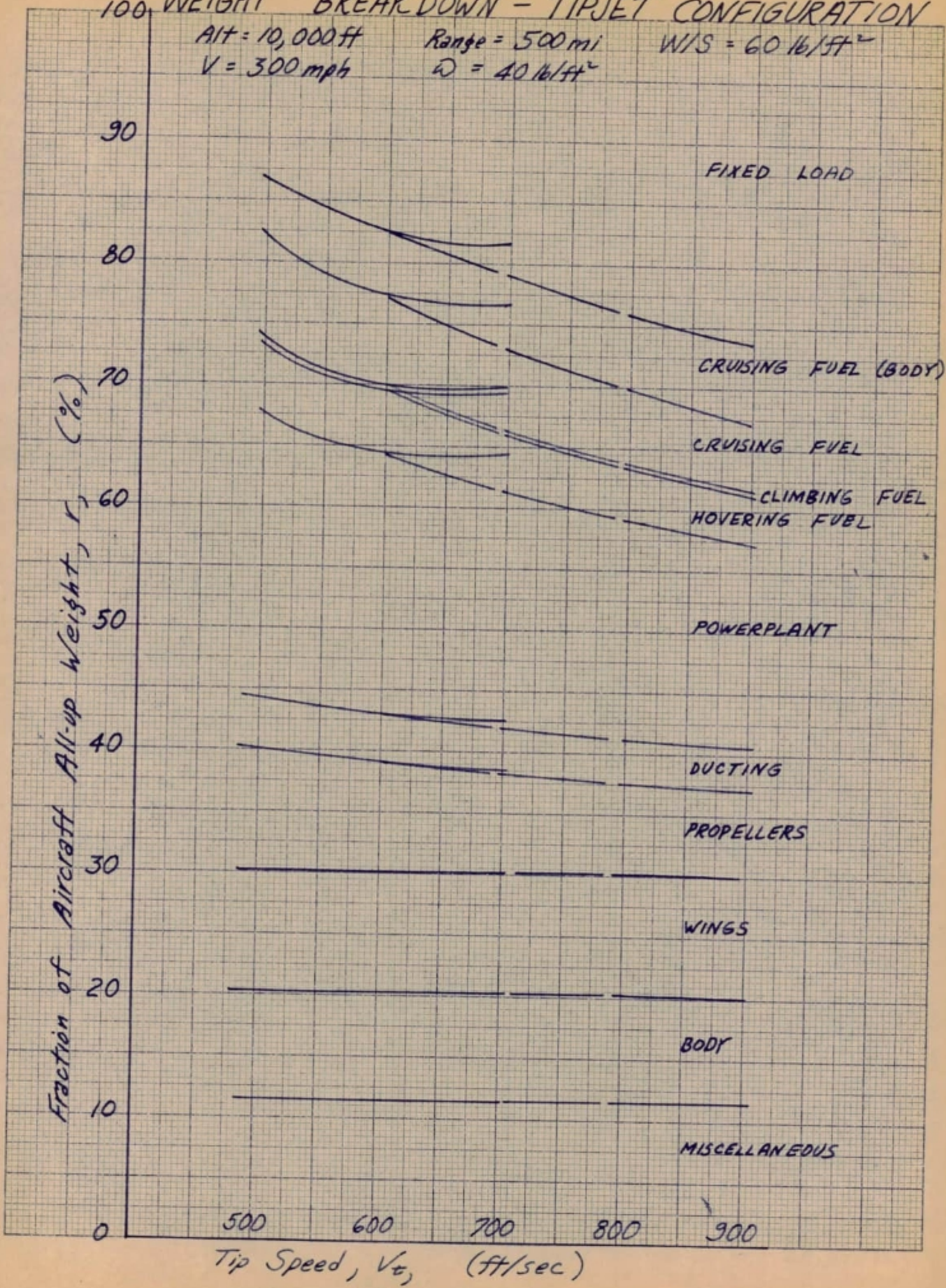
Tipjet Tip Speeds



K&E KENLETT'S ENGINE CO. MADE IN U.S.A. 323-15  
 10 X 10 TO THE 1/2 INCH

# WEIGHT BREAKDOWN - TIPJET CONFIGURATION

Alt = 10,000 ft      Range = 500 mi      W/S = 60 lb/ft<sup>2</sup>  
 V = 300 mph       $\omega = 40$  lb/ft<sup>2</sup>



K&E  
 KENTLETTER & ROBER CO.  
 10 X 10 TO THE 1/2 INCH  
 MADE IN U.S.A.  
 329-15

# WEIGHT BREAKDOWN - TUBOPROP CONFIGURATION

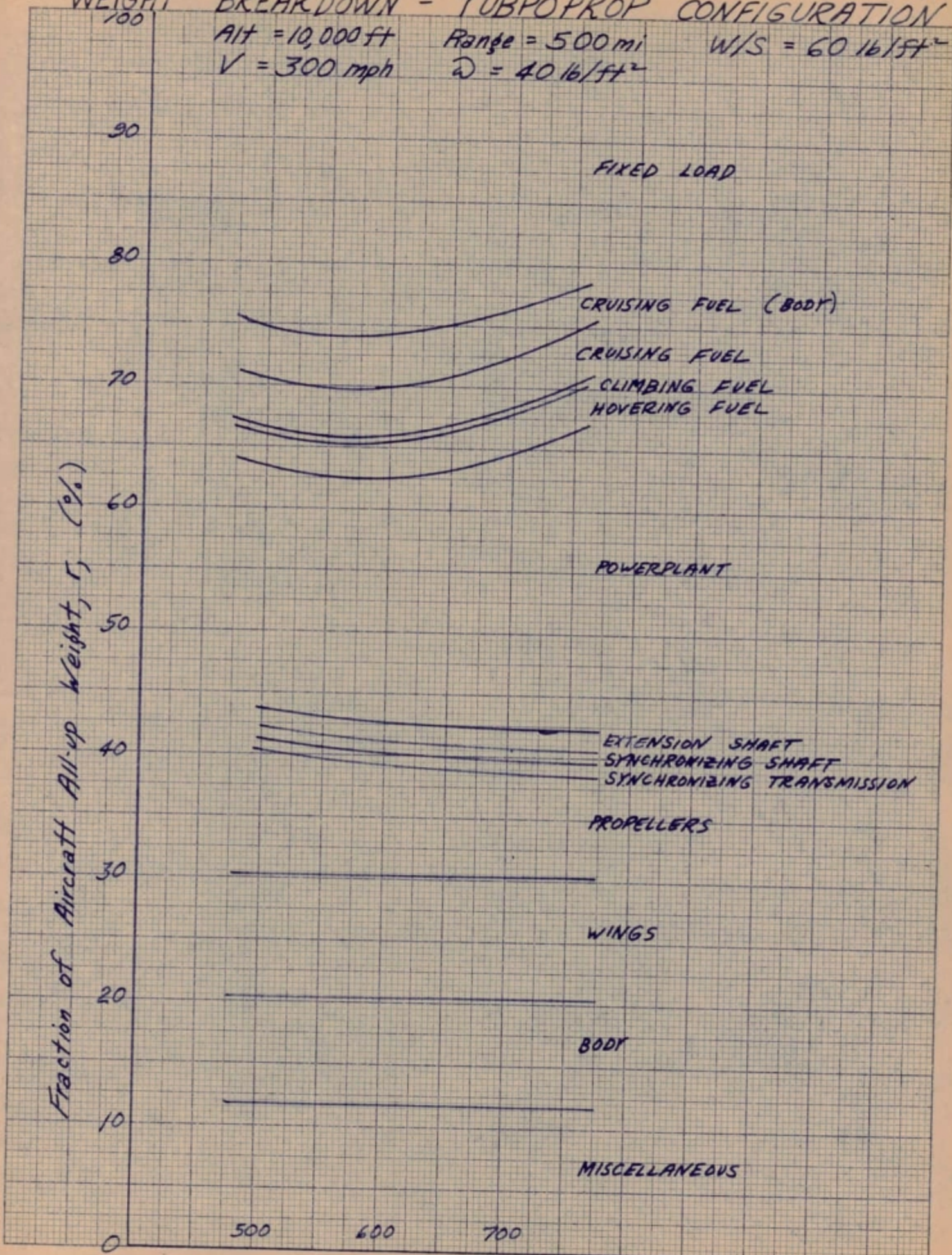
Alt = 10,000 ft  
V = 300 mph

Range = 500 mi  
 $\omega = 40 \text{ lb/ft}^2$

W/S = 60 lb/ft<sup>2</sup>

Fraction of Aircraft All-up Weight,  $\gamma$ , (%)

Tip Speed,  $V_t$  (ft/sec)



K&E  
KENDALL & ERBE CO.  
10 X 10 TO THE 1/2 INCH  
MILITARY  
320-15