

Matching Chart Example

By

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This report is an example of how a *matching chart* would be compiled for the purposes of designing an inter-theater tactical transport aircraft with austere Short Take-Off and Landing (STOL) field capability. This document was compiled for educational purposes only and has not been subjected to any formal checks.

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NOMENCLATURE & SYMBOLS

a — Speed of Sound
 \bar{q} — Dynamic Pressure
AEO — All Engines Operating
AMC — Air Mobility Command
AR — Aspect Ratio
ATM — Air Traffic Management
CBR — California Bearing Ratio
 C_D — Drag Coefficient
 C_{Di} — Induced Drag Coefficient
 C_{Do} — Zero Lift Drag Coefficient
 c_f — Skin Friction Coefficient
CGR — Climb Gradient Requirement
 C_L — Coefficient of Lift
 C_{Lmax} — Maximum Coefficient of Lift
CONUS — Continental United States
e — Oswald's Efficiency Factor
FAR — Federal Aviation Regulation
FDAV — Future Deployable Armoured Vehicle
M — Mach number
 M_{ff} — Mission Fuel Fraction
MIL — Military
MTOW — Maximum Take-Off Weight
N — Number of Engines
OEI — One Engine Inoperative
P — Pressure
R — Specific Gas Constant
RC — Rate of Climb
RFP — Request For Proposal
S — Wing Area
 S_{FL} — Field Length
SL — Sea Level

STOL — Short Take-Off and Landing
 S_{wet} — Wetted Area
T — Temperature or Thrust
TOP₂₅ — Take-Off Parameter Relating to FAR 25
 T_{REQ} — Thrust Required
USAF — United States Air Force
 V_A — Approach Speed
 V_{LFO} — Speed at Lift-Off
 V_S — Stall Speed
 V_{SA} — Stall Speed at Approach
 V_{SL} — Stall Speed at Landing
 V_{STO} — Stall Speed at Take-Off
W — Arbitrary Weight
 W_{crew} — Crew Weight
 W_E — Empty Weight
 W_F — Mission Fuel Weight
 $W_{\text{F(res)}}$ — Fuel Reserves Required For The Mission
 $W_{\text{F(used)}}$ — Fuel Actually Used During The Mission
 W_L — Landing Weight
 W_{OE} — Operating Weight Empty
 W_{PL} — Payload Weight
 W_{tfo} — Trapped Fuel and Oil Weight
 W_{TO} — Take-off Gross Weight
 ρ — Density
 σ — Density Ratio

1 INTRODUCTION

There exists a requirement in the USAF AMC for an inter-theater tactical transport with austere STOL field capability. The USAF aspires to gain flexibility in landing sites of its rapid deployment unit such that it can position FDAV's in areas of opportunity and not be constrained by the requirement to operate strictly in dedicated air fields. The vehicle must also hold the ability to harmoniously operate within national and international air space by possessing commercial airliner speeds and cruise altitudes.

The objective of majority of missions will be to transport FDAV's with austere STOL field capability. However, the aircraft will also need to be capable of performing an alternative mission, namely a transoceanic ferry mission which can deliver different type of payload and operate within a greater radius of action. The aircraft will deploy from CONUS to other non-austere initial deployment locations. It is desirable, but not required, that in-flight refuelling is provided so that the range-payload envelope is increased.

1.1 Mission Specification

- Payload:
 - (a) FDAV — Mass: 30 tonnes = 66 139 lb;
 - (b) Ferry — Mass: 10 tonnes = 22 046 lb;
 - (c) Crew — Mass: 3 members at 200 lb each = 600 lb.
- Range:
 - (a) FDAV — 500 nm;
 - (b) Ferry — 3 200 nm;
 - (c) Loiter — 45 min at 5 000 ft;
 - (d) Diversion — 150 nm.
- Cruise altitude: 30 000 ft (minimum).
- Cruise speed: $M_{\text{cruise}} \geq 0.8$.
- Climb: Initial climb to cruise altitude starting at MTOW.
- Take-off: 2 500 ft balanced take-off field length at SL and hot operation (35° C). See FAR 25.
- Landing:
 - (a) FDAV — 2 500 ft balanced landing field length at SL and 25 knot crosswind with a 5 knot tailwind component;
 - (b) Ferry — 2 000 ft balanced landing field length at SL.

2 CALCULATIONS

The following methodology of calculating relevant parameters closely follows the guidelines listed in Roskam (1985)^[1]. This publication was used because it is applicable to military transport aircraft, such as the one specified in the RFP.

2.1 Estimating W_{TO} , W_E and W_F

To calculate the values of take-off, empty and fuel weight, we will use the procedure outlined in Roskam (1985):

1) Determine W_{PL}

We will assume that since this is a military transport aircraft, each crew member will weigh 200 lb (gear included) and since the RFP makes no reference to baggage, we will exclude this from further calculations. In addition to this, where applicable, there will be two sets of equations accounting for each mission.

$$\text{For FDAV: } W_{PL} = 66\,139 + 3 \times 200 = 66\,739 \text{ lb} \quad (2.1)$$

$$\text{For Ferry: } W_{PL} = 22\,046 + 3 \times 200 = 22\,646 \text{ lb} \quad (2.2)$$

2) Guess a likely value of W_{TO}

After a brief literature review, it was found that Lockheed-Georgia's C-141B was a currently operating aircraft bearing most resemblance to the vehicle being analysed in this paper.

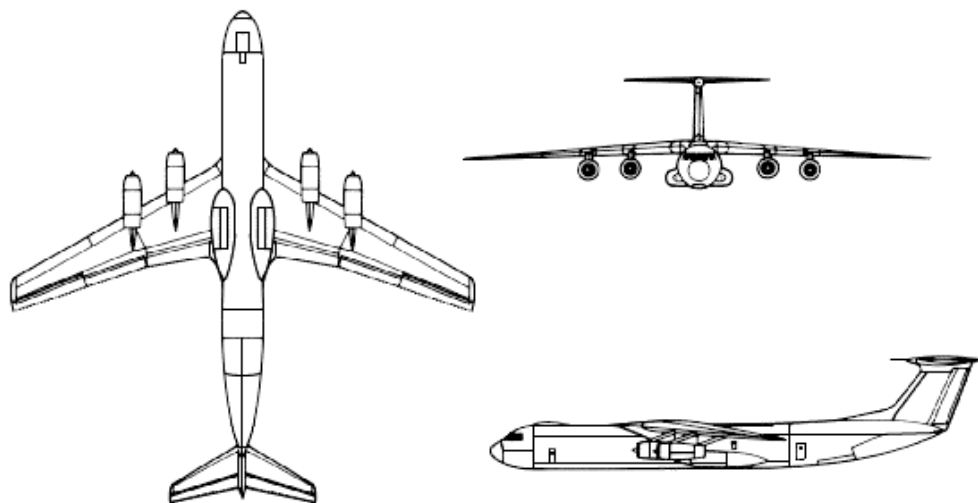


Figure 2-1 — Three-view of Lockheed-Georgia C-141B^[2]

Hence, the data for this aircraft will be used where values of various parameters need to be guessed^[2].

$$W_{TO} = 323\,100 \text{ lb}$$

3) Determine W_F

$$W_F = W_{F(used)} + W_{F(res)} \quad (2.3)$$

A *fuel-fraction* method described in Roskam (1985) will be used in the following calculation to discover a value for equation (2.3).

Phase 1: Engine start and warm-up. Initial weight is W_{TO} and final weight is W_1 .

$$M_{ff} = \frac{W_1}{W_{TO}} = 0.99 \quad (2.4)$$

Phase 2: Taxi. Initial weight is W_1 and final weight is W_2 .

$$M_{ff} = \frac{W_2}{W_1} = 0.99 \quad (2.5)$$

Phase 3: Take-off. Initial weight is W_2 and final weight is W_3 .

$$M_{ff} = \frac{W_3}{W_2} = 0.995 \quad (2.6)$$

Phase 4: Climb to cruise altitude and accelerate to cruise speed. Initial weight is W_3 and final weight is W_4 .

$$M_{ff} = \frac{W_4}{W_3} = 0.98 \quad (2.7)$$

A portion of range will be used for climb. Assuming a velocity of 290 knots for climb and an initial climb rate to of 2 920 ft/min^[3], it would take 10 minutes to reach an altitude of 30 000 ft. The range in this phase of flight can then be calculated from:

$$R_{\text{climb}} = \left(\frac{10}{60} \right) \times 290 = 48 \text{ nm} \quad (2.8)$$

Phase 5: Cruise. Initial weight is W_4 and final weight is W_5 . RFP calls for $M_{\text{cruise}} \geq 0.8$ at 30 000 ft altitude which gives 471 knots^[4]. Using Breguet's range equation and average values listed in Roskam (1985) Table 2.2, we find:

For FDAV:

$$R_{cr} = \left(\frac{V}{c_j} \right)_{cr} \times \left(\frac{L}{D} \right)_{cr} \times \ln \left(\frac{W_4}{W_5} \right)$$

$$500 - 48 = \left(\frac{471}{0.7} \right) \times 16 \times \ln \left(\frac{W_4}{W_5} \right) \quad (2.9)$$

$$\frac{W_4}{W_5} = 1.1015$$

Therefore for FDAV,

$$M_{ff} = \frac{W_5}{W_4} = 0.959 \quad (2.10)$$

And for Ferry:

$$M_{ff} = \frac{W_5}{W_4} = 0.746 \quad (2.11)$$

Phase 6: Loiter will be omitted for simplification purposes.

Phase 7: Descent. Initial weight is W_5 and final weight is W_7 .

$$M_{ff} = \frac{W_7}{W_5} = 0.99 \quad (2.12)$$

Phase 8: Landing, taxi and shutdown. Initial weight is W_7 and final weight is W_8 .

$$M_{ff} = \frac{W_8}{W_7} = 0.992 \quad (2.13)$$

Finally we may calculate a value for mission fuel-fraction:

For FDAV:

$$M_{ff} = \frac{W_8 W_7 W_5 W_4 W_3 W_2 W_1}{W_7 W_5 W_4 W_3 W_2 W_1 W_{TO}}$$

$$= 0.992 \times 0.99 \times 0.959 \times 0.98 \times 0.995 \times 0.99 \times 0.99$$

$$= 0.9 \quad (2.14)$$

$$W_{F(used)} = W_{TO} (1 - M_{ff})$$

$$= W_{TO} \times (1 - 0.9)$$

$$= 0.1 W_{TO} \quad (2.15)$$

For Ferry:

$$M_{ff} = 0.7 \quad (2.16)$$

$$W_{F(used)} = 0.3W_{TO} \quad (2.17)$$

Since the RFP does not make any references to the amount of fuel needed for reserves, this piece of information will be omitted. Therefore, we have:

$$\text{For FDAV: } W_F = 0.1W_{TO}$$

$$\text{For Ferry: } W_F = 0.3W_{TO}$$

4) Determine tentative W_{OE}

$$W_{OE(tent)} = W_{TO} - W_F - W_{PL} \quad (2.18)$$

For FDAV:

$$W_{OE(tent)} = 323\,100 - 0.1 \times 323\,100 - 66\,739 = 224\,051 \text{ lb} \quad (2.19)$$

For Ferry:

$$W_{OE(tent)} = 203\,524 \text{ lb} \quad (2.20)$$

5) Determine tentative W_E

$$W_{E(tent)} = W_{OE(tent)} - W_{tfo} - W_{crew} \quad (2.21)$$

It has been suggested by Roskam (1985) to use 0.5% of W_{TO} for W_{tfo} . Also, since W_{crew} has already been accounted in equations (2.1) and (2.2), it will be omitted from equation (2.21). Hence:

For FDAV:

$$W_{E(tent)} = 224\,051 - 0.005 \times 323\,100 = 222\,436 \text{ lb} \quad (2.22)$$

For Ferry:

$$W_{E(tent)} = 201\,909 \text{ lb} \quad (2.23)$$

6) Determine allowable value of W_E

Using equation 2.16 and in Roskam (1985) and appropriate references listed in the text, we find allowable value for W_E :

$$W_E = 10^{\frac{\log_{10} W_{TO} - A}{B}} \quad (2.24)$$

Where values A and B are given in Roskam (1985) for military transport aircraft. Hence,

$$W_E = 10^{\frac{\log_{10} 323\,100 - 0.2009}{1.1037}} = 149\,184 \text{ lb} \quad (2.25)$$

Clearly there is a large difference between $W_{E(tent)}$ and W_E for both missions. More iterations with different values of W_{TO} had to be made to achieve convergence. It was found from further investigation that $W_{TO} = 290\,000 \text{ lb}$ yielded a satisfactory result.

The three values of primary interest are now given as:

$$W_{TO} = 290\,000 \text{ lb}$$

$$W_E = 135\,267 \text{ lb}$$

$$W_F = 24\,500 \text{ lb for FDAV and } 73\,500 \text{ lb for Ferry mission}$$

2.2 Sizing to Stall, Take-off and Landing Requirements

1) Sizing to stall requirements

FAR 25 applicable aircraft have no stall requirements.

2) Sizing to take-off requirements

From equation 3.8 in Roskam (1985), we find:

$$TOP_{25} = \frac{2\,500}{37.5} = 66.7 \text{ lb/ft}^2 \quad (2.26)$$

At SL conditions with temperature of 38° C, we have for density ratio:

$$\sigma = \frac{\rho}{\rho_{SL}} = \frac{\left(\frac{P}{RT}\right)}{\rho_{SL}} = \frac{\left(\frac{101\,325}{287 \times 311.15}\right)}{1.225} = 0.926251 \quad (2.27)$$

From equation 3.7 in Roskam (1985), we find:

$$\frac{\left(\frac{W}{S}\right)_{TO}}{C_{L_{MAXTO}} \left(\frac{T}{W}\right)_{TO}} = 66.7 \times 0.926251 = 61.78 \text{ lb/ft}^2 \quad (2.28)$$

By using the typical values of $C_{L_{MAXTO}}$ found in Table 3.1 of Roskam (1985), we can plot a relationship of thrust-to-weight ratio versus wing loading at take-off conditions. This chart is can be found in the *Appendix* on page 5-21.

3) Sizing to landing distance requirements

Table 3.3 in Roskam (1985) lists typical values for landing weight to take-off weight ratio. In the case of military transport aircraft, this is given as 0.76. Therefore we can write:

$$W_L = 0.76W_{TO} \quad (2.29)$$

From equation 3.16 in Roskam (1985):

For FDAV:

$$V_A = \sqrt{\frac{S_{FL}}{0.3}} = \sqrt{\frac{2500}{0.3}} = 91.3 \text{ kts} \quad (2.30)$$

For Ferry:

$$V_A = 81.6 \text{ kts} \quad (2.31)$$

From equation 3.15 in Roskam (1985), we get:

For FDAV:

$$V_{SL} = \frac{V_A}{1.3} = \frac{91.3}{1.3} = 70.23 \text{ kts} \quad (2.32)$$

For Ferry:

$$V_{SL} = 62.8 \quad (2.33)$$

Using the values from equations (2.32) and (2.33) for substitution into equation 3.1 in Roskam (1985) yields:

For FDAV:

$$\frac{2\left(\frac{W}{S}\right)_L}{0.002377C_{L_{MAX}L}} = 119^2 \quad (2.34)$$

$$\left(\frac{W}{S}\right)_L = \frac{119^2 \times 0.002377C_{L_{MAX}L}}{2} = 16.83C_{L_{MAX}L}$$

For Ferry:

$$\left(\frac{W}{S}\right)_L = \frac{106^2 \times 0.002377C_{L_{MAX}L}}{2} = 13.35C_{L_{MAX}L} \quad (2.35)$$

Now from (2.29), we can get the following relation:

For FDAV:

$$\left(\frac{W}{S}\right)_{TO} = \frac{16.83}{0.76}C_{L_{MAX}L} = 22.1C_{L_{MAX}L} \quad (2.36)$$

For Ferry:

$$\left(\frac{W}{S}\right)_{TO} = \frac{13.35}{0.76}C_{L_{MAX}L} = 17.6C_{L_{MAX}L} \quad (2.37)$$

The chart of thrust-to-weight ratio versus wing loading at landing conditions is given in *Appendix* on page 5-22.

4) Construction of drag polar

Using Roskam's (1985) equation 3.22, we get:

$$\begin{aligned}
 S_{wet} &= 10^{c+d \log_{10} W_{TO}} \\
 &= 10^{0.1628+0.7316 \log_{10} 290\,000} \\
 &= 14\,424.2 \text{ ft}^2
 \end{aligned} \tag{2.38}$$

From figure 3.21 (b) in Roskam (1985) we find that for 14 424.2 ft² wetter area, and an average value of 0.003 for c_f , the corresponding equivalent parasite area is approximately 45 ft². It will be assumed based on C-141's performance characteristics that the wing loading is 100.1 lb/ft² [5]. Hence an approximate wing area would be 2 897.1 ft². It will also be assumed that aspect ratio and Oswald's Efficiency Factor are 8 and 0.85, respectively. Therefore, with all our calculated and assumed information, we can work out the zero lift drag coefficient and the drag coefficient as follows:

$$\begin{aligned}
 C_D &= C_{D_o} + \frac{\overbrace{C_{D_i}}^{C_L^2}}{\pi A e} \\
 &= \frac{f}{S} + \frac{C_L^2}{\pi A e} \\
 &= \frac{45}{2\,897.1} + \frac{1}{\pi \times 8 \times 0.85} C_L^2 \\
 &= 0.015533 + 0.04681 C_L^2
 \end{aligned} \tag{2.39}$$

By varying the value of C_L , we can use the relation found in (2.39) to plot a graph of C_D versus C_L . This chart can be found in the *Appendix* on page 5-23.

5) Sizing to climb requirements

There are two conditions which must be accounted for in the design process: aircraft operating with all available engines and aircraft operating with one inoperative engine. For the former, thrust-to-weight ratio can be described by:

$$\left(\frac{T}{W} \right)_{AEO} = \frac{1}{L/D} + CGR \tag{2.40}$$

For the latter case, thrust-to-weight ratio is given by:

$$\left(\frac{T}{W} \right)_{OEI} = \frac{N}{N-1} \left[\frac{1}{L/D} + CGR \right] \tag{2.41}$$

Drag polar information at different flight configurations must be first determined in order to size to climb requirements. Roskam (1985) table 3.6 was used to compile the following data:

Table 2-1 — Drag Polar at Various Configurations

Configuration	C_{D0}	A	e	C_{Di}	C_{Lmax}
<i>Clean</i>	0.0155	8	0.85	$\frac{C_L^2}{21.36}$	1.8
<i>TO Flaps</i>	0.0305	8	0.80	$\frac{C_L^2}{20.11}$	2.2
<i>L Flaps</i>	0.0755	8	0.75	$\frac{C_L^2}{18.85}$	3
<i>Gear Down</i>	increment of 0.015	8	no effect	no effect	no effect

Since the aircraft must meet the prerequisites of FAR 25, the following section will investigate various conditions of CGR for the specified aviation requirements. We will use the following method of calculation:

1. Find the critical value of CGR and the fraction of appropriate speed;
2. Use the C_L specified for that flight condition (from *Table 2-1*) and divide by appropriate speed fraction (from step 1);
3. Substitute the new value of C_L into the drag polar (from *Table 2-1*);
4. To find the ratio of (L/D), use the new values of (C_L/C_D);
5. Using equation (2.40) or (2.41), find the appropriate (T/W);
6. Correct for temperature difference to find the correct, required (T/W).

FAR 25.111 (OEI) — Initial Climb Segment Requirement:

$CGR > 0.017$ (for 4 engines), at $V_1 = 1.2V_{STO}$.

$$\frac{C_L}{\left(\frac{V_1}{V_{STO}}\right)} = \frac{2.2}{1.2^2} = 1.53$$

$$C_D = C_{D0} + C_{Di} = 0.0305 + \frac{1.53^2}{20.11} = 0.147$$

$$\frac{C_L}{C_D} = \frac{1.53}{0.147} = 10.400 = \frac{L}{D}$$

$$\begin{aligned} \left(\frac{T}{W}\right)_{OEI} &= \frac{N}{N-1} \left[\frac{1}{L/D} + CGR \right] \\ &= \frac{4}{4-1} \left[\frac{1}{10.400} + 0.017 \right] = 0.150 \end{aligned}$$

FAR 25.121 (OEI) — Transition Segment Climb Requirement:

CGR > 0.005, between V_{LFO} (assumed $1.1V_{STO}$) and V_2 ($1.2V_{STO}$)

$$\frac{C_L}{\left(\frac{V}{V_{STO}}\right)} = \frac{2.2}{1.1^2} = 1.820$$

$$C_D = C_{D_o} + C_{D_i} = 0.0305 + \frac{1.820^2}{20.11} = 0.195$$

$$\frac{C_L}{C_D} = \frac{1.820}{0.195} = 9.340 = \frac{L}{D}$$

$$\begin{aligned} \left(\frac{T}{W}\right)_{OEI} &= \frac{4}{3} \left[\frac{1}{9.340} + 0.005 \right] \\ &= 0.149 \end{aligned}$$

$$\frac{C_L}{\left(\frac{V}{V_{STO}}\right)} = \frac{2.2}{1.2^2} = 1.53$$

$$C_D = C_{D_o} + C_{D_i} = 0.0305 + \frac{1.53^2}{20.11} = 0.147$$

$$\frac{C_L}{C_D} = \frac{1.53}{0.147} = 10.400 = \frac{L}{D}$$

$$\begin{aligned} \left(\frac{T}{W}\right)_{OEI} &= \frac{4}{3} \left[\frac{1}{10.400} + 0.005 \right] \\ &= 0.134 \end{aligned}$$

Clearly the condition at V_{LFO} dominates.

FAR 25.121 (OEI) — Second Segment Climb Requirement:

CGR > 0.03, at $V_2 = 1.2V_{STO}$

$$\frac{C_L}{\left(\frac{V}{V_{STO}}\right)} = \frac{2.2}{1.2^2} = 1.528$$

$$C_D = C_{D_o} + C_{D_i} = 0.0305 + \frac{1.528^2}{20.11} = 0.147$$

$$\frac{C_L}{C_D} = \frac{1.528}{0.147} = 10.425 = \frac{L}{D}$$

$$\begin{aligned} \left(\frac{T}{W}\right)_{OEI} &= \frac{4}{3} \left[\frac{1}{10.425} + 0.03 \right] \\ &= 0.168 \end{aligned}$$

FAR 25.121 (OEI) — En-route Climb Requirement:

CGR > 0.017, at speed of 1.25V_S

$$\frac{C_L}{\left(\frac{V}{V_{STO}}\right)} = \frac{1.8}{1.25^2} = 1.152$$

$$C_D = C_{D_o} + C_{D_i} = 0.0155 + \frac{1.152^2}{21.36} = 0.078$$

$$\frac{C_L}{C_D} = \frac{1.152}{0.078} = 14.840 = \frac{L}{D}$$

$$\left(\frac{T}{W}\right)_{OEI} = \frac{4}{3} \left[\frac{1}{14.840} + 0.017 \right] = 0.113$$

FAR 25.119 (AEO) — Balked (Go-Around) Landing Requirement 1:

CGR > 0.032, at speed of 1.3V_S (also note that W_L = 0.76W_{TO})

$$\frac{C_L}{\left(\frac{V}{V_{STO}}\right)} = \frac{3}{1.3^2} = 1.775$$

$$C_D = C_{D_o} + C_{D_i} = 0.0755 + \frac{1.775^2}{18.85} = 0.243$$

$$\frac{C_L}{C_D} = \frac{1.775}{0.243} = 7.315 = \frac{L}{D}$$

$$\left(\frac{T}{W}\right)_{AEO} = \frac{1}{0.76\left(\frac{L}{D}\right)} + CGR = \frac{1}{0.76 \times 7.315} + 0.032 = 0.212$$

FAR 25.121 (OEI) — Balked (Go-Around) Landing Requirement 2:

CGR > 0.027, at speed of no more than 1.5V_{SA}

$$\frac{C_L}{\left(\frac{V}{V_{STO}}\right)} = \frac{\left(\frac{1.8 + 2.2 + 3}{3}\right)}{1.5^2} = 1.037$$

$$C_D = C_{D_o} + C_{D_i} = 0.0755 + \frac{1.037^2}{18.85} = 0.133$$

$$\frac{C_L}{C_D} = \frac{1.037}{0.133} = 7.797 = \frac{L}{D}$$

$$\left(\frac{T}{W}\right)_{OEI} = \frac{4}{3} \left[\frac{1}{7.797} + 0.027 \right] = 0.207$$

It appears that *FAR 25.119 (AEO) — Balked (Go-Around) Landing Requirement 1* is the most critical one for this aircraft. Hence a value of $(T/W)_{AEO(Landing)} = 0.212$ will be adopted for purposes of design.

6) Sizing to cruise speed requirements

From four fundamental forces acting on an aircraft at cruise, we have:

$$T_{REQ} = C_D \bar{q} S \quad (2.42)$$

and

$$W_{cruise} = C_L \bar{q} S \quad (2.43)$$

Assuming a parabolic drag polar,

$$\begin{aligned} T_{REQ} &= \frac{C_{Do} \bar{q} S}{W_{cruise}} + \frac{W_{cruise}}{q S \pi A e} \\ &= \frac{C_{Do} S \rho V^2}{2 W_{cruise}} + \frac{2 W_{cruise}}{\rho V^2 S \pi A e} \\ &= \frac{C_{Do} S \rho M^2 a^2}{2 W_{cruise}} + \frac{2 W_{cruise}}{\rho M^2 a^2 S \pi A e} \end{aligned} \quad (2.44)$$

Using reference [6], speed of sound was calculated at 994.4 ft/s at $M = 0.8$ and an altitude of 30 000 ft. We can now work out a value for dynamic pressure using the density of air at altitude from equation (2.27). The value that is obtained is approximately 694 lb/ft². Due to the high value of Mach number, drag rise effects must also be accounted for. Roskam's (1985) Figure 3.32 gives a rapid method for estimating drag rise at a given Mach number. For the aircraft in this paper, an approximate drag rise of 0.0025 was calculated. This adjusts our parasitic drag from equation (2.39) in the following way:

$$C_{Do} = 0.015533 + 0.0025 = 0.018033 \quad (2.45)$$

With this information, we can use equation (2.44) to find a relation between (T/W) and (W/S) for cruise speed sizing:

$$\left(\frac{T}{W} \right)_{REQ} = \frac{12.515}{\left(\frac{W}{S} \right)} + 6.745e-05 \times \left(\frac{W}{S} \right) \quad (2.46)$$

A plot of this relation is given in the *Appendix* on page 5-24.

3 CONCLUSION

Overlaying all but plot on page 5-23 (since this plot is in different unit) will give a graphical representation of the requirements and various configurations that a designer may wish to choose to analyse. Depending on the requirements of the RFP, different points may be chosen for the preliminary design stage. The chart attached to the *Appendix* on page 5-25 shows the chosen point for the aircraft in question.

For take-off requirements, we need drag to be as low as possible and lift as high as possible. Plot on page 5-23 shows that for C_L values up to approximately 1.5, drag values remain relatively low. Therefore, we can choose a value of 2.4 for which we can get a high lift at a low cost of drag. Since we are working with a military aircraft, fuel efficiency is not at the top of the priority list.

For landing requirements we need high coefficient of drag since the landing distance is very short. Therefore by increasing drag, we will be able to bring the aircraft to rest in a short distance. A value of C_L 1.6 was chosen since it will produce little lift but sufficient amount of drag.

For cruise speed we need to have high wing loading so that cruise speed can remain high as C_L value is reduced. Working in the range within 100 lb/ft² for (W/S) will produce a high enough lift and a low (T/W) ratio. This is desirable since the condition at which weight is reduced and thrust is increased will produce better fuel economy as there is less drag being produced.

The design point favours average values for coefficients of lift and drag and hence difficult engineering does not need to be carried out. This will also place the aircraft in safe operation. The following table makes a summary of the most important parameters discovered in this report:

Table 3-1 — Summary of Results

Parameter	Value
<i>Take-Off Weight</i>	290 000 lb
<i>Empty Weight</i>	135 267 lb
<i>Fuel Weight</i>	24 500 lb
$C_{Lmax, clean}$	1.8
$C_{Lmax, Take-Off}$	2.2
$C_{Lmax, Landing}$	3
<i>Aspect Ratio</i>	8
<i>Wing Area</i>	2 897.1 ft ²

4 REFERENCES

[1] Roskam, J 1985 *Airplane Design — Part I: Preliminary Sizing of Airplanes*, Roskam Aviation and Engineering Corporation, Kansas.

[2] Military Analysis Network 1999, Federation of American Scientists, Washington, viewed on 16 September, 2007, <<http://www.fas.org/man/dod-101/sys/ac/c-141.htm>>.

[3] Aerospaceweb.org 1997, United States of America, viewed on 16 September, 2007, <<http://www.aerospaceweb.org/aircraft/transport-m/c141/>>.

[4] Tom Benson 2007, National Aeronautics and Space Administration, Cleveland, viewed on 17 September, 2007, <<http://www.grc.nasa.gov/WWW/K-12/airplane/mach.html>>.

[5] Wikipedia 2007, Wikimedia Foundation, Inc, United States of America, viewed on 18 September, 2007, <http://en.wikipedia.org/wiki/C-141_Starlifter>.

[6] Tom Benson 2007, National Aeronautics and Space Administration, Cleveland, viewed on 21 September, 2007, <<http://www.grc.nasa.gov/WWW/K-12/airplane/sound.html>>.

5 APPENDIX

[1] (T/W) vs (W/S) for Take-Off — page 5-21;

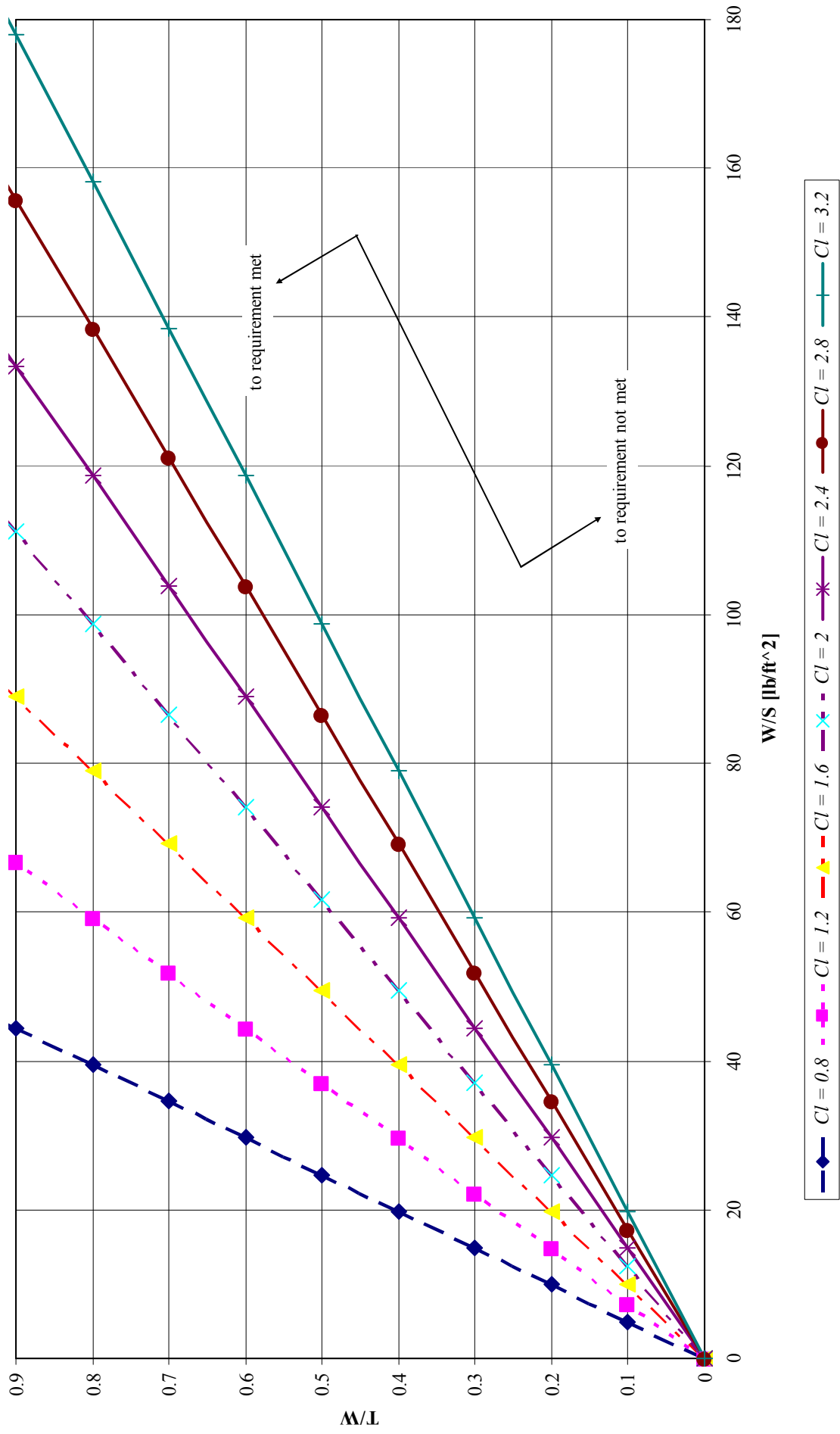
[2] (T/W) vs (W/S) for Landing — page 5-22;

[3] C_D vs C_L — page 5-23;

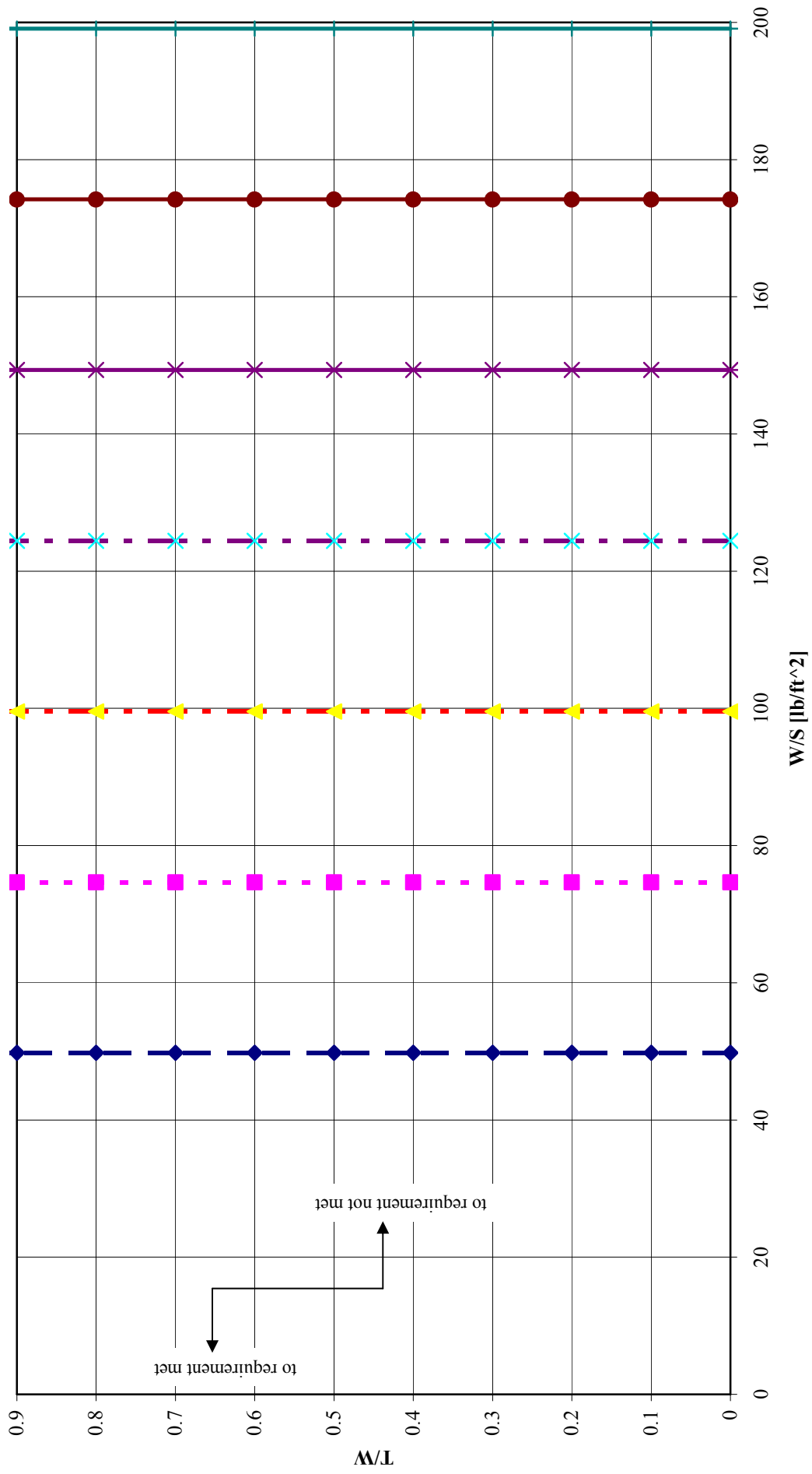
[4] (T/W) vs (W/S) for Cruise Speed Sizing — page 5-24;

[5] Matching Chart — page 5-25.

(T/W) vs (W/S) for Take-Off



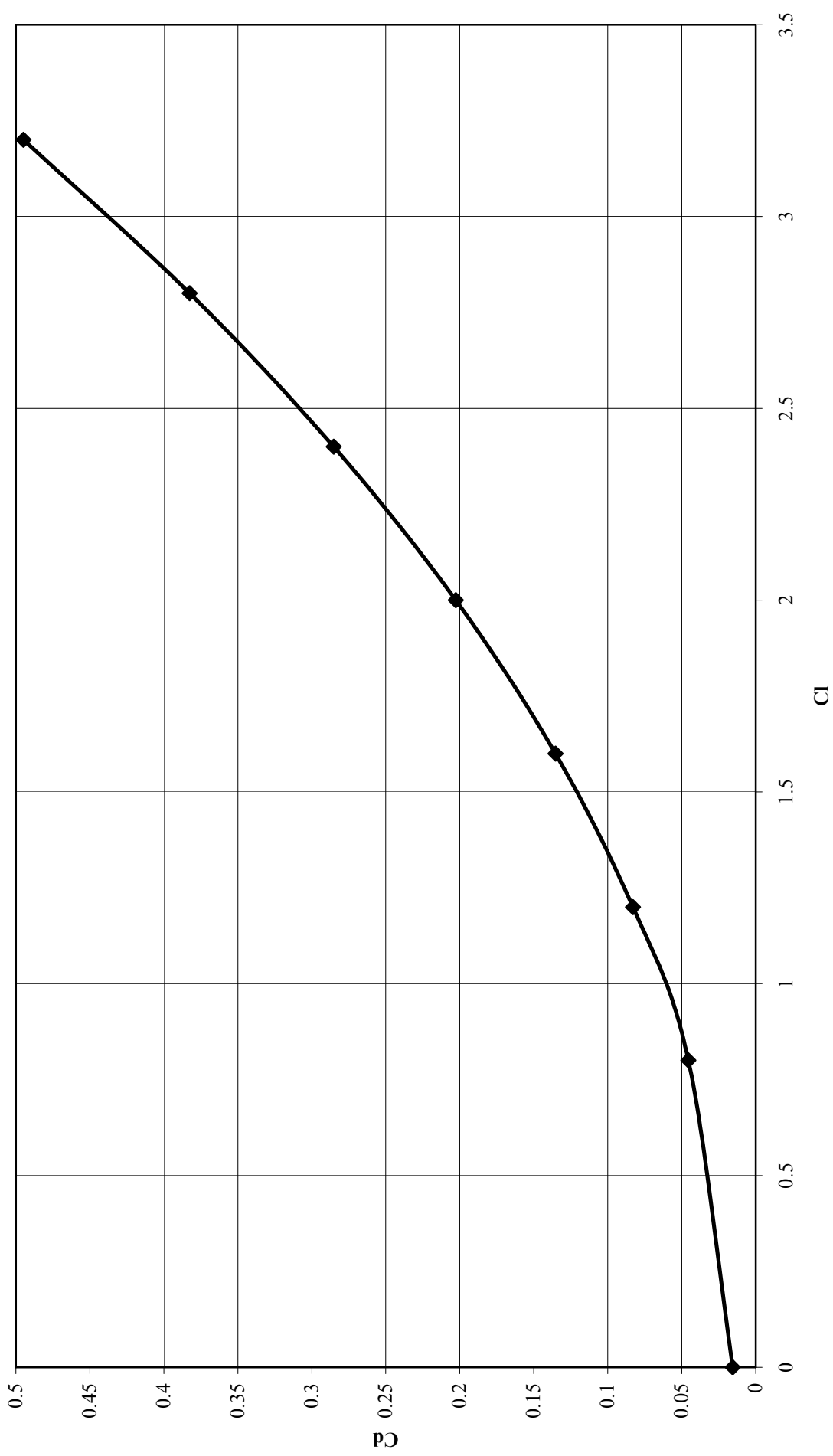
(T/W) vs (W/S) for Landing



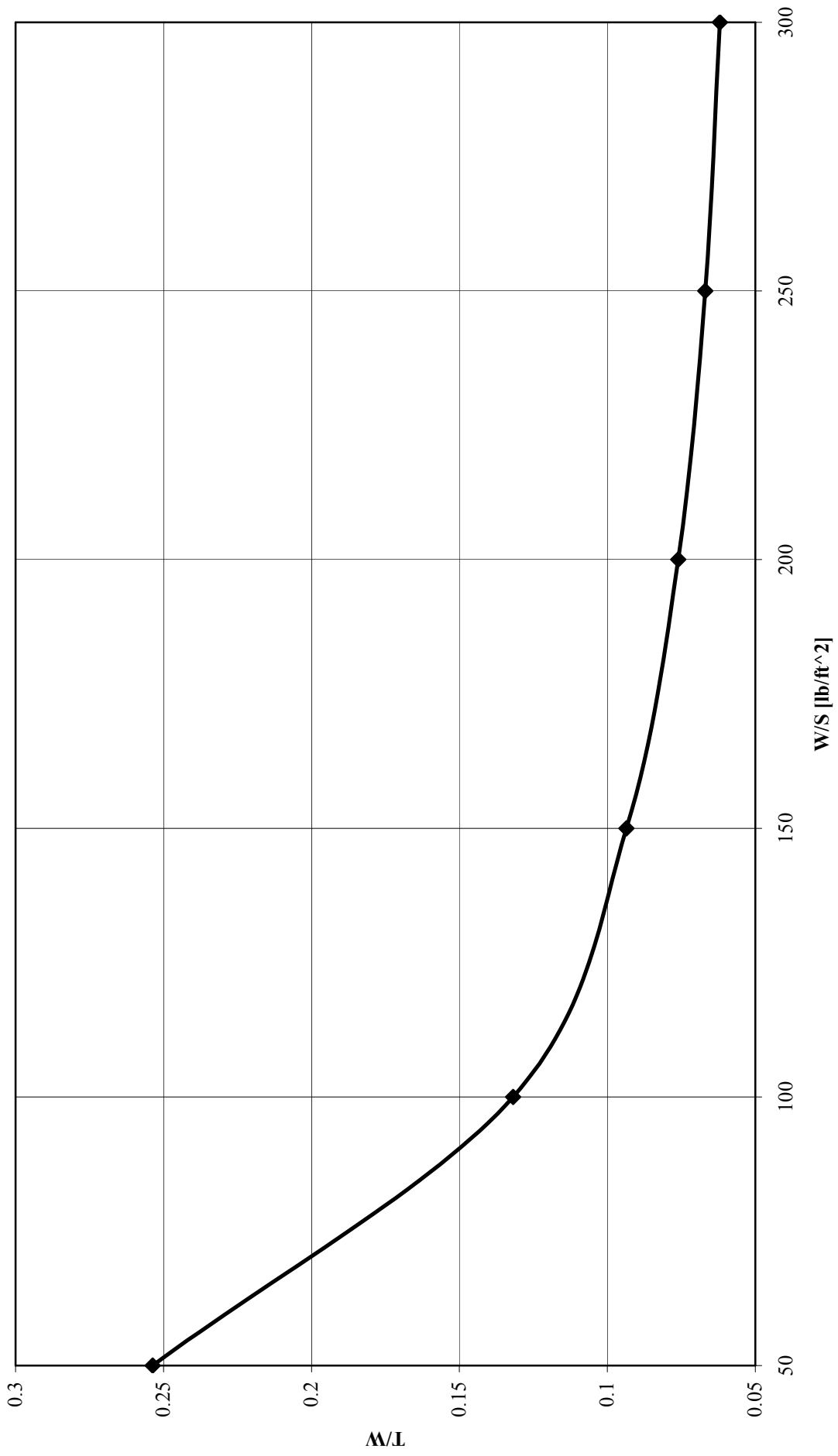
to requirement met

to requirement not met

Cd vs Cl



(T/W) vs (W/S) for Cruise Speed Sizing



Matching Chart

