```matlab
clc;close all;clear

format long g

%% Constants

% Only change this section for different configuration

Conventional_airfoil = 0; % 0 for supercritical airfoil

Advanced_technology = 0; % Adjust weight after weight loop: 1 for composite
material, 2 for aluminum/lithium structure

Debug = 0;

Swept_angle = 0;

AR = 3;

AR_max = 20;

AR_step_size = 1;

% C_L loop constants

Velocity_approach = 135; % knot

Mach_cruise = 0.80;

Range = 3500; % Nmi

max_percent_fuel_at_landing = 45/100; % max % fuel at landing, 75% for sample
calculation

% TOFL constants

Number_of_engine = 2;

Takeoff_field_length = 6900;

% Weight constants

K_w = 1.01; % 1.03 for fuselage engine

Eta = 1.5*2.5; % Ultimate load factor

Constant_Weight_fuselage = 1; % 1.1 if 3-class international 1 if not

Taper_ratio = 0.35;

K_f = 11.5; % constant for PAX > 135

PAX = 210; % slang for passenger

N_seats_abreast = 6;
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```
N_aisles = 2; % standard
K_ts = 0.17; % 0.17 for wing engine, 0.25 for fuselage engine
Weight_cargo = 8000; % lb
N_flight_crew = 2;
N_cabin_attendants = 6;
% Drag calculation constants
Fuselage_length = 179; % from tip to tail [ft]
Fuselage_diameter = 20;
% Climb cosntants
Initial_cruise_altitude = 35000; % [ft]
% Thrust check at top climb constant
JT8D = 0; % 1 for JT8D engine and 0 for JT9D engine
%% Loops
fprintf("Swept angle = %.4f degree.\n", Swept_angle)
AR_number_of_steps = (AR_max - AR) / AR_step_size;
AR_list = [];
DOC_list = [];
for i = 1:AR_number_of_steps
   Adjustment_Weight_to_Thrust_ratio = 0;
   fail = 1;
   while fail == 1
       fail = 0;
       % Initalize loop variable
       Ajustment_Factor_Fuel = 0.02;
       Range_all_out_guess = 0;
       Range_all_out = 1E10;
       Range_iteration_limit = 5000;
       % if AR > 13
       %     Range_iteration_limit = 5000;
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    % end
    Range_iteration = 0;
    while (abs(Range_all_out-Range_all_out_guess) > 100) && Range_iteration
< Range_iteration_limit
        % abs(Range_all_out-Range_all_out_guess)
        Range_iteration = Range_iteration + 1;
        if Debug == 1
            fprintf("Debug. Currently in Range loop.\n")
        end
        %% C_L loop
        % Initalize loop variable
        C_L = 0.58;
        C_L_final = 0.1;
        C_L_iteration_limit = 5000;
        C_L_iteration = 0;
        % While loop boundary and iteration taken from Psuedo_Code.m
        while (abs(C_L_final-C_L) > .005) && (C_L_iteration <
C_L_iteration_limit)
            C_L_iteration = C_L_iteration + 1;
            if Conventional_airfoil == 1
                Delta_Mach_div = -0.348*C_L + 0.191;
            elseif Conventional_airfoil == 0
                Delta_Mach_div = -0.179 + 1.07*C_L + -1.84*C_L^2 +
0.873*C_L^3;
            else
                fprintf("Airfoil must be either conventional or
supercritical.")
            end
            % 3. Calculate Divergent Mach number
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Mach_div = (Mach_cruise + 0.004) - Delta_Mach_div;

% 4. Use Figure 1a to find t/c

if Conventional_airfoil == 1

    t_c_0 = -0.634*Mach_div + 0.572;

    t_c_10 = -0.616*Mach_div + 0.563;

    t_c_15 = -0.593*Mach_div + 0.551;

    t_c_20 = -0.565*Mach_div + 0.537;

    t_c_25 = -0.533*Mach_div + 0.519;

    t_c_30 = -0.504*Mach_div + 0.505;

    t_c_35 = -0.468*Mach_div + 0.486;

    t_c_40 = -0.428*Mach_div + 0.464;

    if (Swept_angle >= 0) && (Swept_angle <= 10)

        t_c = ((Swept_angle - 0) / (10 - 0)) * (t_c_10 - t_c_0)
+ t_c_0;

    elseif (Swept_angle >= 10) && (Swept_angle < 15)

        t_c = ((Swept_angle - 10) / (15 - 10)) * (t_c_15 -
t_c_10) + t_c_10;

    elseif (Swept_angle >= 15) && (Swept_angle < 20)

        t_c = ((Swept_angle - 15) / (20 - 15)) * (t_c_20 -
t_c_15) + t_c_15;

    elseif (Swept_angle >= 20) && (Swept_angle < 25)

        t_c = ((Swept_angle - 20) / (25 - 20)) * (t_c_25 -
t_c_20) + t_c_20;

    elseif (Swept_angle >= 25) && (Swept_angle < 30)

        t_c = ((Swept_angle - 25) / (30 - 25)) * (t_c_30 -
t_c_25) + t_c_25;

    elseif (Swept_angle >= 30) && (Swept_angle < 35)

        t_c = ((Swept_angle - 30) / (35 - 30)) * (t_c_35 -
t_c_30) + t_c_30;
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                    elseif (Swept_angle >= 35) && (Swept_angle <= 40)
                        t_c = ((Swept_angle - 35) / (40 - 35)) * (t_c_40 -
t_c_35) + t_c_35;
                    end
                elseif Conventional_airfoil == 0
                    t_c_0 = 3.49 + -8.26*Mach_div + 4.98*Mach_div^2;
                    t_c_5 = 3.36 + -7.87*Mach_div + 4.71*Mach_div^2;
                    t_c_10 = 3.17 + -7.32*Mach_div + 4.32*Mach_div^2;
                    t_c_15 = 3.08 + -6.97*Mach_div + 4.04*Mach_div^2;
                    t_c_20 = 2.86 + -6.29*Mach_div + 3.55*Mach_div^2;
                    t_c_25 = 3.07 + -6.64*Mach_div + 3.68*Mach_div^2;
                    t_c_30 = 3.47 + -7.34*Mach_div + 3.96*Mach_div^2;
                    t_c_35 = 5.35 + -11.3*Mach_div + 6.11*Mach_div^2;
                    t_c_40 = 11.8 + -24.9*Mach_div + 13.3*Mach_div^2;
                    if (Swept_angle >= 0) && (Swept_angle <= 5)
                        t_c = ((Swept_angle - 0) / (5 - 0)) * (t_c_5 - t_c_0) +
t_c_0;
                    elseif (Swept_angle >= 5) && (Swept_angle < 10)
                        t_c = ((Swept_angle - 5) / (10 - 5)) * (t_c_10 - t_c_5)
+ t_c_5;
                    elseif (Swept_angle >= 10) && (Swept_angle < 15)
                        t_c = ((Swept_angle - 10) / (15 - 10)) * (t_c_15 -
t_c_10) + t_c_10;
                    elseif (Swept_angle >= 15) && (Swept_angle < 20)
                        t_c = ((Swept_angle - 15) / (20 - 15)) * (t_c_20 -
t_c_15) + t_c_15;
                    elseif (Swept_angle >= 20) && (Swept_angle < 25)
                        t_c = ((Swept_angle - 20) / (25 - 20)) * (t_c_25 -
t_c_20) + t_c_20;
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                elseif (Swept_angle >= 25) && (Swept_angle < 30)
                    t_c = ((Swept_angle - 25) / (30 - 25)) * (t_c_30 - t_c_25) + t_c_25;
                elseif (Swept_angle >= 30) && (Swept_angle < 35)
                    t_c = ((Swept_angle - 30) / (35 - 30)) * (t_c_35 - t_c_30) + t_c_30;
                elseif (Swept_angle >= 35) && (Swept_angle <= 40)
                    t_c = ((Swept_angle - 35) / (40 - 35)) * (t_c_40 - t_c_35) + t_c_35;
                end
            else
                fprintf("Conventional_airfoil has to be either 1 or 0.\n")
            end
            % 5. Constant: cos^2 t/c AR. Use constant and Fig 3 to find CL_max
            temp = cosd(Swept_angle)^2 * t_c^2 * AR;
            C_L_max_landing = 2.19 + 11.1*temp + -23.2*temp^2;
            C_L_max_takeoff = 1.18 + 12.9*temp + -30.8*temp^2;
            % 6. Calculate wing loading at landing
            sigma = 0.953; % some kind of ratio related to altitude
            WL_landing = (Velocity_approach/1.3)^2*(sigma*C_L_max_landing/296);
            % 7. Crusing velocity and All out range
            Velocity_cruise = Mach_cruise * 576.4; % [kts] sqrt(gamma R T) = 576.4
            Range_all_out = Range + 200 + 0.75*Velocity_cruise;
            % 8. Use Figure 4 (Engine JT8D) to find fuel weight to take off weight ratio
```

```
                Weight_fuel_takeoff_JT8D = 0.0209 + 1.04E-04*Range_all_out + 
-5.51E-09*Range_all_out^2 + Ajustment_Factor_Fuel;
                % 9. Engine type is JT9D, not JT8D
                if JT8D == 0 % Engine is JT9D
                    SFC_JT9D = 0.61;
                    SFC_JT8D = 0.78;
                    Weight_fuel_takeoff = Weight_fuel_takeoff_JT8D * 
(SFC_JT9D/SFC_JT8D) + 0.0257;
                elseif JT8D == 1
                    Weight_fuel_takeoff = Weight_fuel_takeoff_JT8D;
                else
                    fprintf("JT8D must be either 0 or 1.")
                end
                % 10. Take off wing loading
                WL_takeoff =  WL_landing / (1 - max_percent_fuel_at_landing * 
Weight_fuel_takeoff);
                % 11. Initial crusing wing loading
                WL_initial_crusing = 0.965 * WL_takeoff;
                % 12. Calculate lift coefficient for initial crusing
                C_L_initial_crusing = WL_initial_crusing / (1481 * 0.2360 * 
Mach_cruise^2);
                C_L_final = C_L_initial_crusing;
                % Conditional Statement to determine whether guess is high or 
low
                if C_L_final>C_L
                    C_L = C_L + 0.01;
                else
                    C_L = C_L - 0.01;
                end
```

```
            end
            if Debug == 1
                fprintf('Debug. End C_L loop...\n');
            end
            %% TOFL
            % Weight to Thurst ratio at 0.7 lift off velocity. Figure 5
            if Number_of_engine == 2
                temp = 28.3*Takeoff_field_length*10^(-3) + -9.09;
            elseif Number_of_engine == 3
                temp = 31.5*Takeoff_field_length*10^(-3) - 7.45;
            elseif Number_of_engine == 4
                temp = 32.5*Takeoff_field_length*10^(-3) + 1.41;
            else
                fprintf("Number_of_engine must be 2-4.")
            end
            Weight_Thrust_0_7_Velocity_liftoff = temp * sigma * C_L_max_takeoff
/ WL_takeoff;
            % 0.7 of Mach number at lift off
            Velocity_liftoff = 1.2 * sqrt((296*WL_takeoff) /
(sigma*C_L_max_takeoff));
            Mach_liftoff = Velocity_liftoff / (661*sqrt(sigma));
            Mach_liftoff_0_7 = 0.7 * Mach_liftoff;
            % Weight to Thrust ratio
            Thrust_JT9D_sea_level_static = 45500; % Sea Level Static Thrust
            Thrust_at_0_7_Mach_liftoff = -24567*Mach_liftoff_0_7 + 42600; % JT9D
            Weight_Thrust = Weight_Thrust_0_7_Velocity_liftoff *
Thrust_at_0_7_Mach_liftoff / Thrust_JT9D_sea_level_static +
Adjustment_Weight_to_Thrust_ratio;
            %% Weight
```

```
% Weight Wing = Weight_Wing * Weight_takeoff^1.195
Weight_wing = 0.00945 * AR^0.8 * (1 + Taper_ratio)^0.25 * K_w *
Eta^0.5 / ( (t_c + 0.03)^0.4 * cosd(Swept_angle) * WL_takeoff^0.695 );
% Weight Fuselage = Weight_fuselage * Weight_takeoff^0.235
l = (3.76*PAX / N_seats_abreast + 33.2) * Constant_Weight_fuselage;
d = (1.75 * N_seats_abreast + 1.58 * N_aisles + 1) *
Constant_Weight_fuselage;
Weight_fuselage = 0.6727 * K_f * l^0.6 * d^0.72 * Eta^0.3;
% Weight landing gear = 0.04 * Weight_takeoff
Weight_landing_gear = 0.04;
% Weight nacelle + Weight pylon = Weight_nacelle_pylon *
Weight_takeoff
Weight_nacelle_pylon = 0.0555 / Weight_Thrust;
% Weight tail surface = 0.1967 * Weight_wing
Weight_tail_surface = (K_ts + 0.08/Number_of_engine);
% Weight tail surface + wing = Weight_tail_surface_wing *
Weight_takeoff^1.195
Weight_tail_surface_wing = (Weight_tail_surface + 1) * Weight_wing;
% Weight power plant = Weight_power_plant * Weight_takeoff
Weight_power_plant = 1/(3.58*Weight_Thrust);
% Weight fuel = Weight_fuel * Weight_takeoff
Weight_fuel = 1.0275 * Weight_fuel_takeoff;
% Weight payload = Weight_payload [lb]
Weight_payload =  215*PAX + Weight_cargo;
% Weight fixed equipment = Weight_fixed_equipment +
0.035*Weight_takeoff
Weight_fixed_equipment = 132 * PAX + 300 * Number_of_engine + 260 *
N_flight_crew + 170* N_cabin_attendants;
% Construct Weight polynomial. a*x^1.195 + b*x^0.235 + c*x + d = 0
```

```
            a = Weight_tail_surface_wing;
            b = Weight_fuselage;
            c = Weight_landing_gear + Weight_nacelle_pylon + Weight_power_plant
+ Weight_fuel + 0.035 - 1;
            d = Weight_payload + Weight_fixed_equipment;
            % Initalize loop variable
            Weight_takeoff = 545000;
            max_iterations = 5e5;
            iteration = 0;
            while abs(a*Weight_takeoff^1.195 + b*Weight_takeoff^0.235 +
c*Weight_takeoff + d) > 100 && iteration < max_iterations
                % Conditional Statement to determine whether guess is high or
low
                if (a*Weight_takeoff^1.195 + b*Weight_takeoff^0.235 +
c*Weight_takeoff + d) > 0
                    Weight_takeoff = Weight_takeoff + 1000;
                else
                    Weight_takeoff = Weight_takeoff - 1000;
                end
                iteration = iteration + 1;
            end
            if Debug == 1
                fprintf('Debug. End Weight loop...\n\n');
            end
            % Weight calculation for advanced technology
            if Advanced_technology == 1
                Weight_takeoff = Weight_takeoff -
Weight_tail_surface_wing*Weight_takeoff^1.195*0.3 -
```

```
Weight_fuselage*Weight_takeoff^0.235*0.15 - (Weight_fixed_equipment +
0.035*Weight_takeoff)*0.1 - Weight_nacelle_pylon * Weight_takeoff * 0.2;
           elseif Advanced_technology == 2
               Weight_takeoff = Weight_takeoff -
Weight_tail_surface_wing*Weight_takeoff^1.195*0.06 -
Weight_fuselage*Weight_takeoff^0.235*0.06;
           end
           % Reference area
           S_ref = Weight_takeoff / WL_takeoff;
           % Span
           Span = sqrt(AR * S_ref);
           % Mean aerodynamic cord
           MAC = S_ref / Span;
           % Thrust
           Thrust = Weight_takeoff / Weight_Thrust;
           Thrust_per_engine = Thrust / Number_of_engine;
           %% Drag calculation
           % Mach = 5 for this section
           % Reynold_over_Lenglth
           Velocity_at_0_5_Mach = 0.5 * 576.4 * 1.688; % convert [kts] to
[ft/s]
           Reynolds_over_Length = 2.852E6 * 0.5; % [1/ft]
           % Copy and paste from drag project Triet code in MAE 158
           % ----- Wing Parasite Drag -----
           Reynolds_wing = Reynolds_over_Length * MAC;                %
Reynolds number (wing)
           C_f_wing = 0.0798 * Reynolds_wing^-0.195;      % Skin friction
coefficient (wing)
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            Z = ((2 - 0.5^2) * cosd(Swept_angle)) / sqrt(1 - 0.5^2 *
cosd(Swept_angle)^2);
            K_wing = 1 + Z * t_c + 100 * t_c^4;  % Form factor
            S_wet_wing = 2*(S_ref - 20*30)*1.02;         % Wetted area from
model (ft^2)
            f_wing = K_wing * C_f_wing * S_wet_wing; % Equivalent profile drag
area
            % ----- Fuselage Parasite Drag -----
            Reynolds_f = Reynolds_over_Length * Fuselage_length;
% Reynolds number (fuselage)
            C_f_f = 0.0798 * Reynolds_f^(-0.195);          % Skin friction
coefficient (fuselage)
            Lf_Df = Fuselage_length / Fuselage_diameter;                       %
Length-to-diameter ratio
            K_f = 2.29 - 0.353 * Lf_Df + 0.038 * Lf_Df^2 - 1.48E-03 * Lf_Df^3; %
Form factor (fuselage)
            S_wet_f = 0.9*pi*Fuselage_diameter*Fuselage_length;
            f_fuselage = K_f * C_f_f * S_wet_f ;            % Equivalent profile
drag area
            % ----- Other Parasite Drag -----
            f_tail_surface = 0.38*f_wing;
            S_wet_nacelle = 2.1*sqrt(Thrust_per_engine)*Number_of_engine;
            f_nacelle = 1.25* C_f_wing *S_wet_nacelle;
            f_pylon = 0.2*f_nacelle;
            % ----- Total Parasite Drag -----
            f_total = 1.06*(f_wing + f_fuselage + f_tail_surface + f_nacelle +
f_pylon);
            C_D_parasite = f_total / S_ref;
            Oswald_Efficiency = 1/ (1.035 + 0.38 * C_D_parasite * pi * AR);
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            Oswald_Efficiency = vpa(Oswald_Efficiency); % format
            %% Climb
            % Calculate climb velocity
            Weight_climb = 0.9825*Weight_takeoff;
            Density_ratio_at_20_35th_cruise_height = 0.5702;
            Velocity_L_D_max = ( 12.9/(f_total*Oswald_Efficiency)^0.25 ) *
sqrt(Weight_climb / (Density_ratio_at_20_35th_cruise_height * Span));
            Velocity_climb = 1.3 * Velocity_L_D_max;
            Mach_climb = Velocity_climb/576.4;
            % Calculate Thrust required
            Drag_compressibility = 0; % no compressibility drag in climbing
            Drag_parasite = Density_ratio_at_20_35th_cruise_height * f_total *
Velocity_climb^2 / 296;
            Drag_induced =
(94.1/(Density_ratio_at_20_35th_cruise_height*Oswald_Efficiency)) *
(Weight_climb / Span)^2 * (1/Velocity_climb^2);
            Thrust_required_climb = Drag_parasite + Drag_induced +
Drag_compressibility;
            % Thrust available per engine
            Thrust_available_at_20k = 15400;
            Specific_fuel_consumption_at_20k = 0.65; % constant varied with
altitude and engine type
            Thrust_available = ( Thrust_per_engine /
Thrust_JT9D_sea_level_static ) * Thrust_available_at_20k;
            Rate_of_climb = 101 * (Number_of_engine * Thrust_available -
Thrust_required_climb) * Velocity_climb / Weight_climb;
            Time_climb = ( Initial_cruise_altitude / Rate_of_climb ) / 60; %
[minutes]
            Range_climb = Velocity_climb * Time_climb; % [nmi]
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            Weight_fuel_climb = Number_of_engine * Thrust_available *
Specific_fuel_consumption_at_20k * Time_climb;
            %% Range
            % Lift coefficient
            Weight_0 = Weight_takeoff - Weight_fuel_climb;
            Weight_1 = (1-Weight_fuel_takeoff)*Weight_takeoff;
            C_L_average_cruise = ( (Weight_0 + Weight_1) / (2*S_ref) ) / (1481 *
0.2360 * Mach_cruise^2);
            % Drag coefficient
            C_D_induced = C_L_average_cruise*C_L_average_cruise/
(pi*AR*Oswald_Efficiency);
            Delta_C_D_compressibility = 0.001;
            C_D_total = C_D_parasite + C_D_induced + Delta_C_D_compressibility;
            % Lift over Drag
            Lift_Drag = C_L_average_cruise/C_D_total;
            % Thurst
            Thrust_required_range = 0.5*(Weight_0 + Weight_1) / Lift_Drag;
            Thrust_required_JT9D = (Thrust_required_range * (
Thrust_JT9D_sea_level_static / Thrust_per_engine ))/ Number_of_engine ;
            % Engine graph at 35k
            Specific_fuel_consumption_at_35k = 0.392*Mach_cruise + 0.30856;
            % Range [nmi]
            Range_cruise = (Velocity_cruise/Specific_fuel_consumption_at_35k) *
Lift_Drag * log(Weight_0 / Weight_1);
            Range_all_out_guess = Range_climb + Range_cruise;
            if Range_all_out_guess < Range_all_out
                Ajustment_Factor_Fuel = Ajustment_Factor_Fuel + 0.01;
            else
                Ajustment_Factor_Fuel = Ajustment_Factor_Fuel - 0.01;
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```
            end
        end
        if Debug == 1
            fprintf("Debug. Range.\n")
        end
        %% Thrust Check at top of climb
        C_L_initial_crusing_thrust_check =
(Weight_0/S_ref)/(1481*0.2360*Mach_cruise^2);
        C_D_induced_thrust_check = C_L_initial_crusing_thrust_check^2/
(pi*AR*Oswald_Efficiency);
        C_D_parasite_thrust_check = f_total/S_ref;
        C_D_total_thrust_check = C_D_parasite_thrust_check +
C_D_induced_thrust_check + Delta_C_D_compressibility;
        Lift_Drag_thrust_check =
C_L_initial_crusing_thrust_check/C_D_total_thrust_check;
        Thrust_required_thrust_check = (Weight_0/Lift_Drag_thrust_check) /
Number_of_engine;
        % Now scale down the above value to that of JT9D:
        Thrust_required_JT9D_thrust_check = Thrust_required_thrust_check * (
Thrust_JT9D_sea_level_static / Thrust_per_engine );
        if JT8D == 1
            Thrust_available_at_35k = 1381*Mach_cruise + 2675;
        else
            Thrust_available_at_35k = 3570*Mach_cruise + 7380;
        end
        if Thrust_required_JT9D_thrust_check > Thrust_available_at_35k
            if Debug == 1
                fprintf('NOT ENOUGH THRUST TOP OF CLIMB\n')
            end
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            fail = 1;
        end
        % Climb gradients
        %% 1st Segment
        C_L_takeoff_segment_1 = C_L_max_takeoff / 1.2^2;
        % C_L_takeoff and Figure 6 to get Delta_C_D_parasite
        temp = C_L_takeoff_segment_1 / C_L_max_takeoff;
        Delta_C_D_parasite_segment_1 = 0.0327 + -0.0707*temp + 0.0893*temp^2 +
-0.151*temp^3 + 0.163*temp^4;
        Delta_C_D_gear = 0.0145;
        C_D_induced_segment_1 = C_L_takeoff_segment_1^2 /
(pi*AR*Oswald_Efficiency);
        C_D_total_segment_1 = C_D_parasite + Delta_C_D_parasite_segment_1 +
Delta_C_D_gear + C_D_induced_segment_1;
        Lift_Drag_segment_1 = C_L_takeoff_segment_1 / C_D_total_segment_1;
        Thrust_required_segment_1 = Weight_takeoff/Lift_Drag_segment_1;
        % Maximum Limit Operating (MLO) dry takeoff thrust
        Thrust_MLO_dry_takeoff_segment_1 = 45479 + -48077*Mach_liftoff +
38144*Mach_liftoff^2;
        Thrust_available_segment_1 = (Thrust_per_engine /
Thrust_JT9D_sea_level_static) * Thrust_MLO_dry_takeoff_segment_1;
        Gradient_1 = ((((Number_of_engine - 1)*(Thrust_available_segment_1)) -
Thrust_required_segment_1) / Weight_takeoff) * 100;
        %% 2nd Segment
        % No Delta_C_D_gear in C_D_total_segment_2
        C_D_total_segment_2 = C_D_parasite + Delta_C_D_parasite_segment_1 +
C_D_induced_segment_1;
        Lift_Drag_segment_2 = C_L_takeoff_segment_1 / C_D_total_segment_2;
        Thrust_required_segment_2 = Weight_takeoff / Lift_Drag_segment_2;
```

```
        Gradient_2 = ((((Number_of_engine - 1) * (Thrust_available_segment_1)) -
Thrust_required_segment_2) / Weight_takeoff) * 100;
        %% 3rd Segment
        C_L_max_clean = 0.191 + 13.1*t_c + -39.5*t_c^2;
        Velocity_segment_3 = 1.2 * (sqrt((296 * WL_takeoff) / (0.9204 *
C_L_max_clean))); % KTS
        Mach_segment_3 = Velocity_segment_3 / 659;
        C_L_segment_3 = C_L_max_clean / (1.2^2);
        C_D_total_segment_3 = C_D_parasite + C_L_segment_3^2 /
(pi*AR*Oswald_Efficiency);
        Lift_Drag_segment_3 = C_L_segment_3 / C_D_total_segment_3;
        Thrust_required_segment_3 = Weight_takeoff / (Lift_Drag_segment_3);
        Thrust_JT9D_Max_Climb_Condition = 37594 + -36139*Mach_segment_3 +
18246*Mach_segment_3^2;
        Thrust_available_segment_3 = (Thrust_per_engine /
Thrust_JT9D_sea_level_static) * Thrust_JT9D_Max_Climb_Condition;
        Gradient_3 = ((((Number_of_engine - 1) * Thrust_available_segment_3) -
Thrust_required_segment_3) / Weight_takeoff) * 100;
        %% Approach
        C_L_approach = C_L_max_takeoff / 1.3^2;
        temp = C_L_approach / C_L_max_takeoff;
        Delta_C_D_parasite_approach = 0.0327 + -0.0707*temp + 0.0893*temp^2 +
-0.151*temp^3 + 0.163*temp^4;
        C_D_total_approach = C_D_parasite + Delta_C_D_parasite_approach +
C_L_approach^2 / (pi*AR*Oswald_Efficiency);
        Lift_Drag_approach = C_L_approach / C_D_total_approach;
        Weight_landing_approach = WL_landing * S_ref;
        Thrust_required_approach = Weight_landing_approach / Lift_Drag_approach;
```

```
        Velocity_approach_segment = sqrt((296 * WL_landing) / (0.953 *
C_L_approach)); % KTS
        Mach_approach = Velocity_approach_segment / 667;
        Thrust_JT9D_Mach_approach_Max_Climb_Condition = -21428*(Mach_approach)^3
+ 43382*(Mach_approach)^2 - 43523*(Mach_approach) + 37935;
        Thrust_available_approach = (Thrust_per_engine /
Thrust_JT9D_sea_level_static) * Thrust_JT9D_Mach_approach_Max_Climb_Condition;
        Gradient_approach = ((Number_of_engine - 1)*Thrust_available_approach -
Thrust_required_approach)*100/Weight_landing_approach;
        %% Landing
        C_L_landing = C_L_max_landing / 1.3^2;
        temp = C_L_landing / C_L_max_landing;
        Delta_C_D_parasite_landing = 0.0411 + -0.0684*temp + 8.83E-03*temp^2 +
0.0784*temp^3;
        C_D_total_approach = C_D_parasite + Delta_C_D_parasite_landing +
Delta_C_D_gear + C_L_landing^2 / (pi*AR*Oswald_Efficiency);
        Lift_Drag_landing = C_L_landing / C_D_total_approach;
        Thrust_required_landing = Weight_landing_approach / Lift_Drag_landing;
        Velocity_landing = Velocity_approach;
        Mach_landing = Velocity_landing/667;
        Thrust_JT9D_Mach_landing_dry = 45479 + -48077*Mach_landing +
38144*Mach_landing^2;
        Thrust_available_landing = (Thrust_per_engine /
Thrust_JT9D_sea_level_static) * Thrust_JT9D_Mach_landing_dry;
        Gradient_landing =(Number_of_engine*Thrust_available_landing -
Thrust_required_landing) * 100 / Weight_landing_approach;
        %% Gradient_check
        if Number_of_engine == 2
            if (Gradient_1 < 0)
```

```
    if Debug == 1
        fprintf('Gradient 1 fail.\n')
    end
    fail = 1;
end
if (Gradient_2 < 2.4)
    if Debug == 1
        fprintf('Gradient 2 fail.\n')
    end
    fail = 1;
end
if (Gradient_3 < 1.2)
    if Debug == 1
        fprintf('Gradient 3 fail.\n')
    end
    fail = 1;
end
if (Gradient_approach < 2.1)
    if Debug == 1
        fprintf('Gradient approach fail.\n')
    end
    fail = 1;
end
if (Gradient_landing < 3.2)
    if Debug == 1
        fprintf('Gradient landing fail.\n')
    end
    fail = 1;
end
```

```
elseif Number_of_engine == 3

    if (Gradient_1 < 0.3)

        if Debug == 1

            fprintf('Gradient 1 fail.\n')

        end

        fail = 1;

    end

    if (Gradient_2 < 2.7)

        if Debug == 1

            fprintf('Gradient 2 fail.\n')

        end

        fail = 1;

    end

    if (Gradient_3 < 1.5)

        if Debug == 1

            fprintf('Gradient 3 fail.\n')

        end

        fail = 1;

    end

    if (Gradient_approach < 2.49)

        if Debug == 1

            fprintf('Gradient approach fail.\n')

        end

        fail = 1;

    end

    if (Gradient_landing < 3.2)

        if Debug == 1

            fprintf('Gradient landing fail.\n')

        end
```

```
        fail = 1;
    end
elseif Number_of_engine == 4
    if (Gradient_1 < 0.5)
        if Debug == 1
            fprintf('Gradient 1 fail.\n')
        end
        fail = 1;
    end
    if (Gradient_2 < 3.0)
        if Debug == 1
            fprintf('Gradient 2 fail.\n')
        end
        fail = 1;
    end
    if (Gradient_3 < 1.7)
        if Debug == 1
            fprintf('Gradient 3 fail.\n')
        end
        fail = 1;
    end
    if (Gradient_approach < 2.7)
        if Debug == 1
            fprintf('Gradient approach fail.\n')
        end
        fail = 1;
    end
    if (Gradient_landing < 3.2)
        if Debug == 1
```

```
                fprintf('Gradient landing fail.\n')
            end
            fail = 1;
        end
    else
        fprintf("Check number of engine. Only 2-4 engines are allowed.\n")
    end
    if fail == 1
        % fprintf("Debug.Fail after Gradient Check.\n")
        Adjustment_Weight_to_Thrust_ratio =
Adjustment_Weight_to_Thrust_ratio + 0.01;
    end
end
%% Direct Operating Cost (DOC)
% Block velocity:
Distance_block = 1.15 * Range;
Time_ground_maneuvering = 0.25; % Hour
Time_descent = 0 ;
Time_additional_miscellaneous = 0.1;
Time_cruise = (Distance_block + 0.02*Distance_block + 20 -
(Range_climb*1.15) - 0 ) / (1.15 * Velocity_cruise);
Velocity_block = Distance_block / (Time_ground_maneuvering + Time_climb +
Time_descent + Time_cruise + Time_additional_miscellaneous);
% Block time
Time_block = Time_ground_maneuvering + Time_climb + Time_descent +
Time_cruise + Time_additional_miscellaneous;
% Block fuel
Fuel_climb = Weight_fuel_climb;
```

```
   Fuel_cruise = Thrust_required_range * Specific_fuel_consumption_at_35k *
Time_cruise;
   Fuel_additional_miscellaneous = Thrust_required_range *
Specific_fuel_consumption_at_35k * Time_additional_miscellaneous;
   Fuel_block = Fuel_climb + Fuel_cruise + Fuel_additional_miscellaneous;
   % Flying operation cost
   % a. Flight Crew
   Payload_in_tons = Weight_payload / 2000; % tons
   Velocity_cruise_in_mph = 1.15 * Velocity_cruise;
   Cost_over_block_hour = 17.849 * (Velocity_cruise_in_mph *
(Weight_takeoff/10^5) )^0.3 + 40.83;
   Cost_light_crew_per_ton_mile = Cost_over_block_hour / (Velocity_block *
Payload_in_tons);
   % b. Fuel and Oil
   Cost_fuel_per_pound = 0.4 * (1 / 6.4);
   Cost_Oil_per_pound = 2.15;
   Cost_fuel_and_oil_per_ton_mile = (1.02 * Fuel_block * Cost_fuel_per_pound +
Number_of_engine * Cost_Oil_per_pound * Time_block * 0.135) / (Distance_block *
Payload_in_tons);
   % C. Hull Insurance
   Weight_airframe = Weight_takeoff - Weight_fuel * Weight_takeoff -
Weight_payload - Weight_power_plant * Weight_takeoff;
   Cost_airframe = 2.4*10^6 + 87.5 * Weight_airframe;
   Cost_per_engine = 590000 + (16 * Thrust_per_engine);
   Cost_total_aircraft = Cost_airframe + Number_of_engine * Cost_per_engine;
   Insurance_Rate = 1/100;
   Utilization_rate_in_flight_hours_per_year = 630 + 4000 / (1 + 1 /
(Time_block + 0.5));
```

```
   Cost_Hull_insurance_per_ton_mile = (Insurance_Rate * Cost_total_aircraft) /
(Utilization_rate_in_flight_hours_per_year * Velocity_block * Payload_in_tons);
   % Direct maintenance
   % a. Airframe labor
   Coefficient_flight_hour_airframe_labor = (4.9169 * log10(Weight_airframe /
1000)) - 6.425;
   Coefficient_flight_cycle_labor = 0.21256 * (log10(Weight_airframe /
1000))^3.7375;
   Time_maintenance_flight = Time_block - Time_ground_maneuvering;
   Labor_rate_per_hour = 8.6;
   Cost_airframe_labor_per_ton_mile = ((Coefficient_flight_hour_airframe_labor
* Time_maintenance_flight + Coefficient_flight_cycle_labor) / (Velocity_block *
Time_block * Payload_in_tons)) * Labor_rate_per_hour;
   % b. Airframe material
   Coefficient_flight_hour_airframe_material = 1.5994 * Cost_airframe / 10^6 +
3.4263;
   Coefficient_flight_cycle_airframe_material = 1.9220 * Cost_airframe / 10^6 +
2.2504;
   Cost_airframe_material_per_ton_mile =
(Coefficient_flight_hour_airframe_material * Time_maintenance_flight +
Coefficient_flight_cycle_airframe_material) / (Velocity_block * Time_block *
Payload_in_tons);
   % c. Engine labor
   Coefficient_flight_hour_engine_labor = (Number_of_engine *
(Thrust_per_engine / 1000)) / ((0.82715 * (Thrust_per_engine / 1000)) +
13.639);
   Coefficient_flight_cycle_engine_labor = 0.2 * Number_of_engine;
```

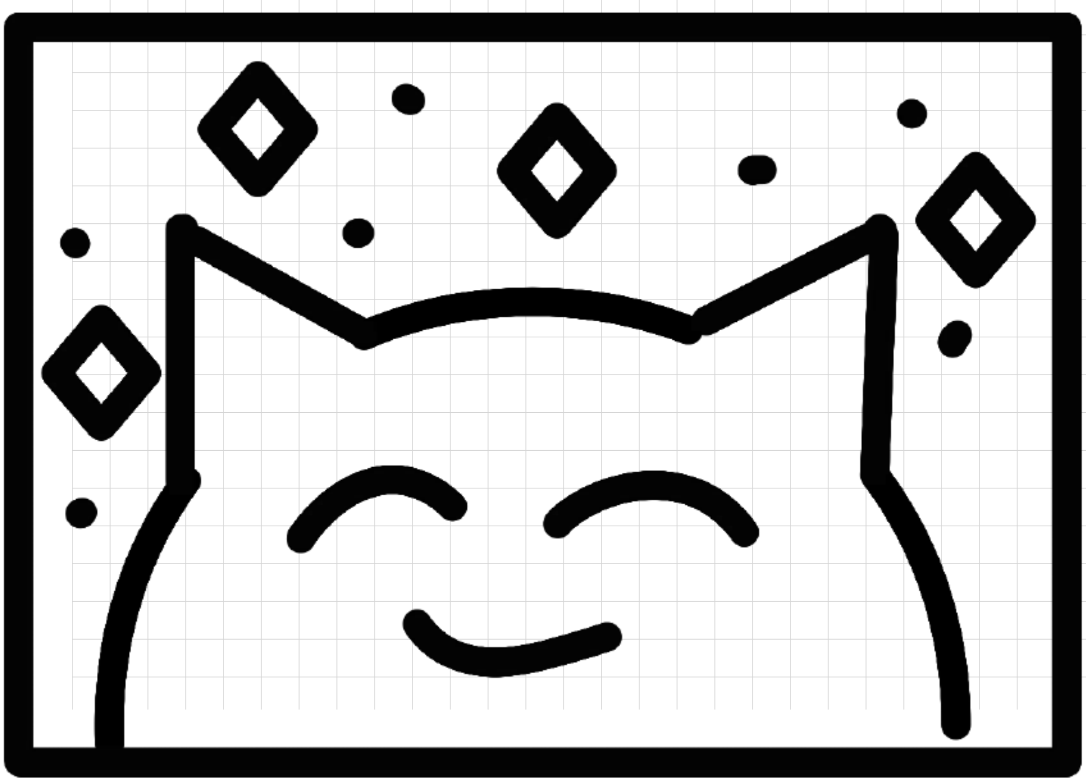
```
    Cost_engine_labor_per_ton_mile = (((Coefficient_flight_hour_engine_labor *
Time_maintenance_flight) + Coefficient_flight_cycle_engine_labor) *
Labor_rate_per_hour) / (Velocity_block * Time_block * Payload_in_tons);
    % d. Engine material
    Coefficient_flight_hour_engine_material = ((28.2353 * Cost_per_engine /
10^6) - 6.5176) * Number_of_engine;
    Coefficient_flight_cycle_engine_material = ((3.6698 * Cost_per_engine /
10^6) + 1.3685) * Number_of_engine;
    Cost_engine_material_per_ton_mile = (Coefficient_flight_hour_engine_material
* Time_maintenance_flight + Coefficient_flight_cycle_engine_material) /
(Velocity_block * Time_block * Payload_in_tons);
    % e. Total maintenance
    Cost_total_maintenance = (Cost_airframe_labor_per_ton_mile +
Cost_airframe_material_per_ton_mile + Cost_engine_labor_per_ton_mile +
Cost_engine_material_per_ton_mile)*2;
    % Depreciation
    Cost_total_maintenance_depreciation = ( Cost_total_aircraft + (0.06 *
(Cost_total_aircraft - (Number_of_engine * Cost_per_engine))) + (0.3 *
Number_of_engine * Cost_per_engine) ) / ( Velocity_block * Payload_in_tons * 14
* Utilization_rate_in_flight_hours_per_year );
    % Total Direct Operating Cost (DOC)
    Direct_operating_cost_per_ton_mile = Cost_light_crew_per_ton_mile +
Cost_fuel_and_oil_per_ton_mile + Cost_Hull_insurance_per_ton_mile +
Cost_total_maintenance + Cost_total_maintenance_depreciation;
    Direct_operating_cost_per_passenger_mile =
Direct_operating_cost_per_ton_mile * Payload_in_tons / PAX;
    DOC = Direct_operating_cost_per_ton_mile;
    DOC_list(end+1) = DOC;
    AR = AR + AR_step_size;
```

```
    AR_list(end+1) = AR;
    fprintf("AR = %.4f\n", AR)
    fprintf("DOC = %.4f\n", DOC)
end
figure;
plot(AR_list, DOC_list, '-o', 'LineWidth', 2, 'MarkerSize', 8);
grid on;
xlabel('Aspect Ratio (AR)');
ylabel('Direct Operating Cost (DOC)');
title('Effect of Aspect Ratio on Direct Operating Cost');
legend('DOC vs AR');
```

MAE 159

ALL HAND CALCULATIONS

TRIET



C_L LOOP

① $M = 0.8$ at $35\,000$ [ft]

Select conventional airfoil $\qquad \Lambda = 35°$, $AR = 8$

② Assume $C_L = 0.5$

From Figure 2

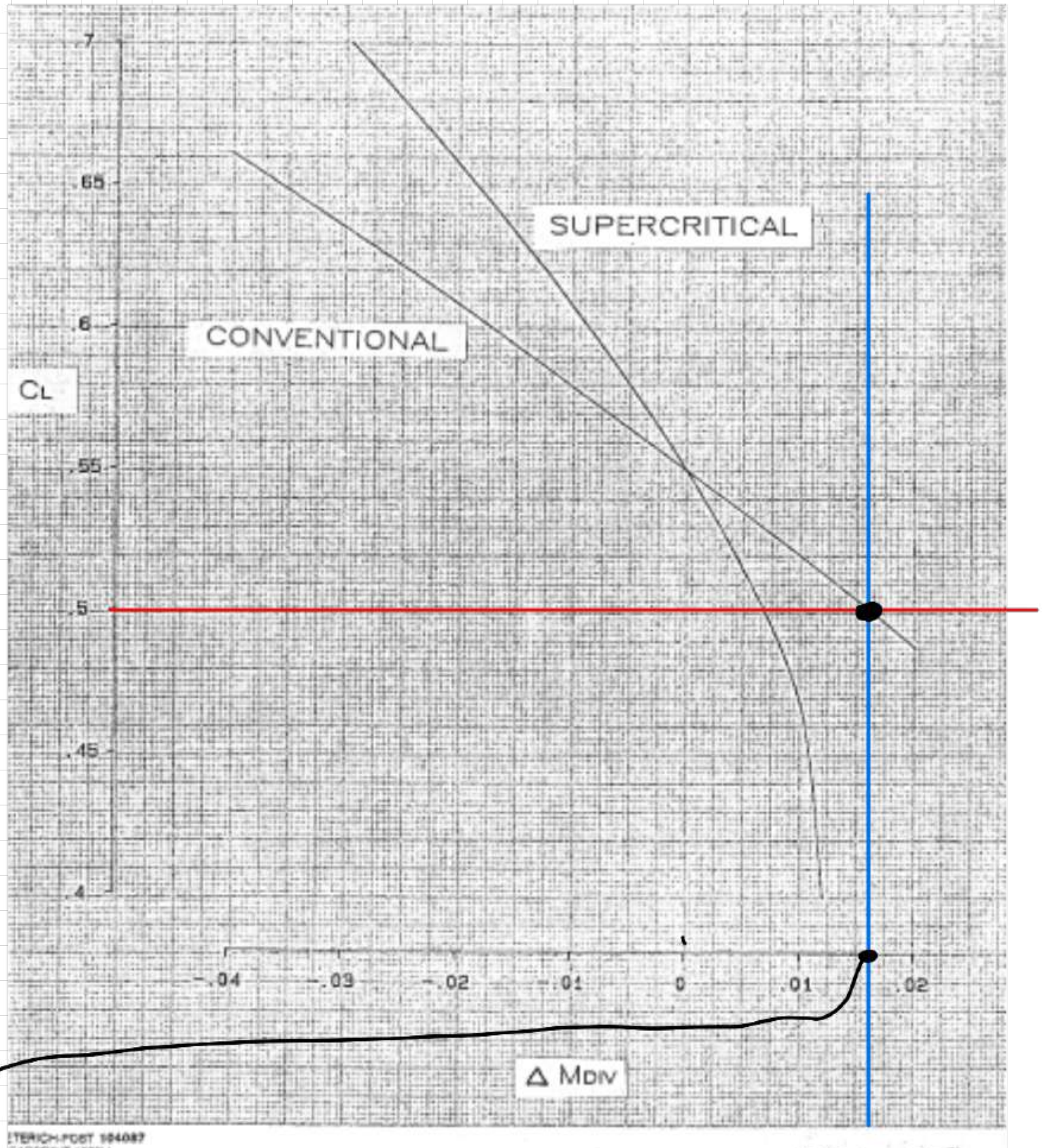


FIGURE 2

$\Delta M_{Div} = 0.016$

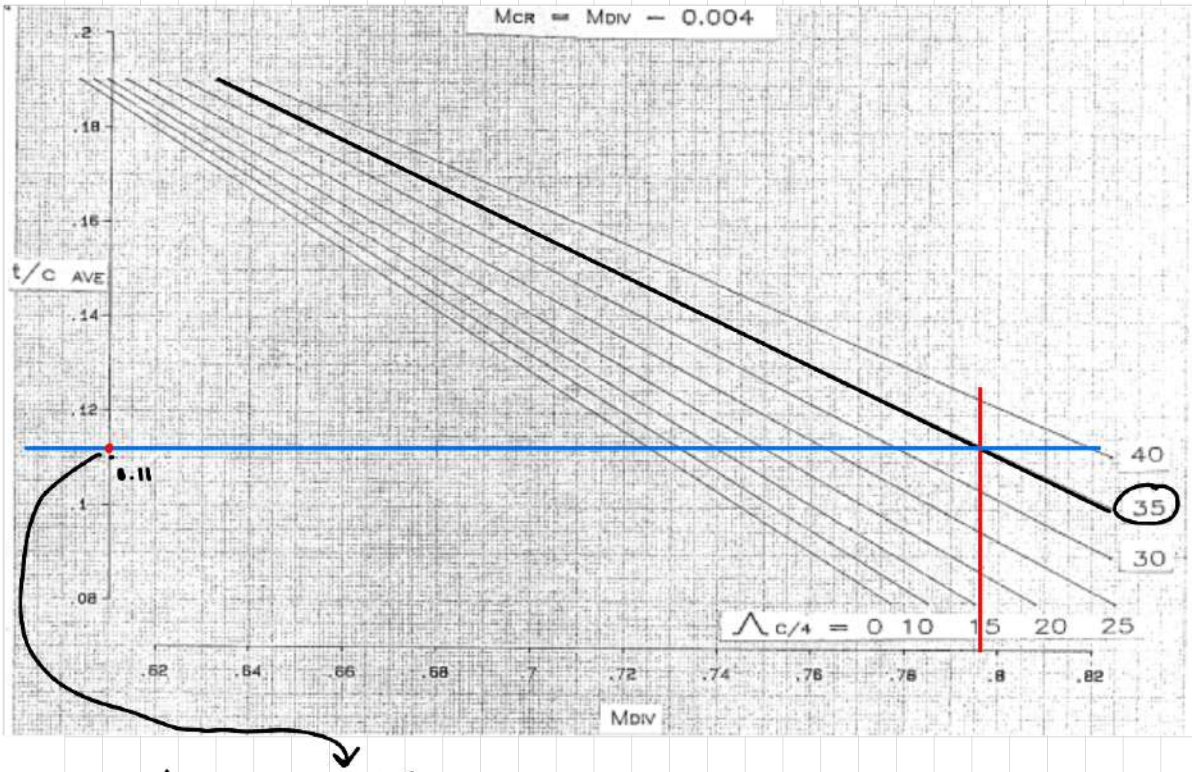
③ $M_{Div} = (M_{cruise} + 0.004) - \Delta M_{Div}$

$= (0.8 + 0.004) - 0.016$

$M_{Div} = 0.788$

④ $\Lambda = 35°$ $M_{Div} = 0.788$

From Figure 1a



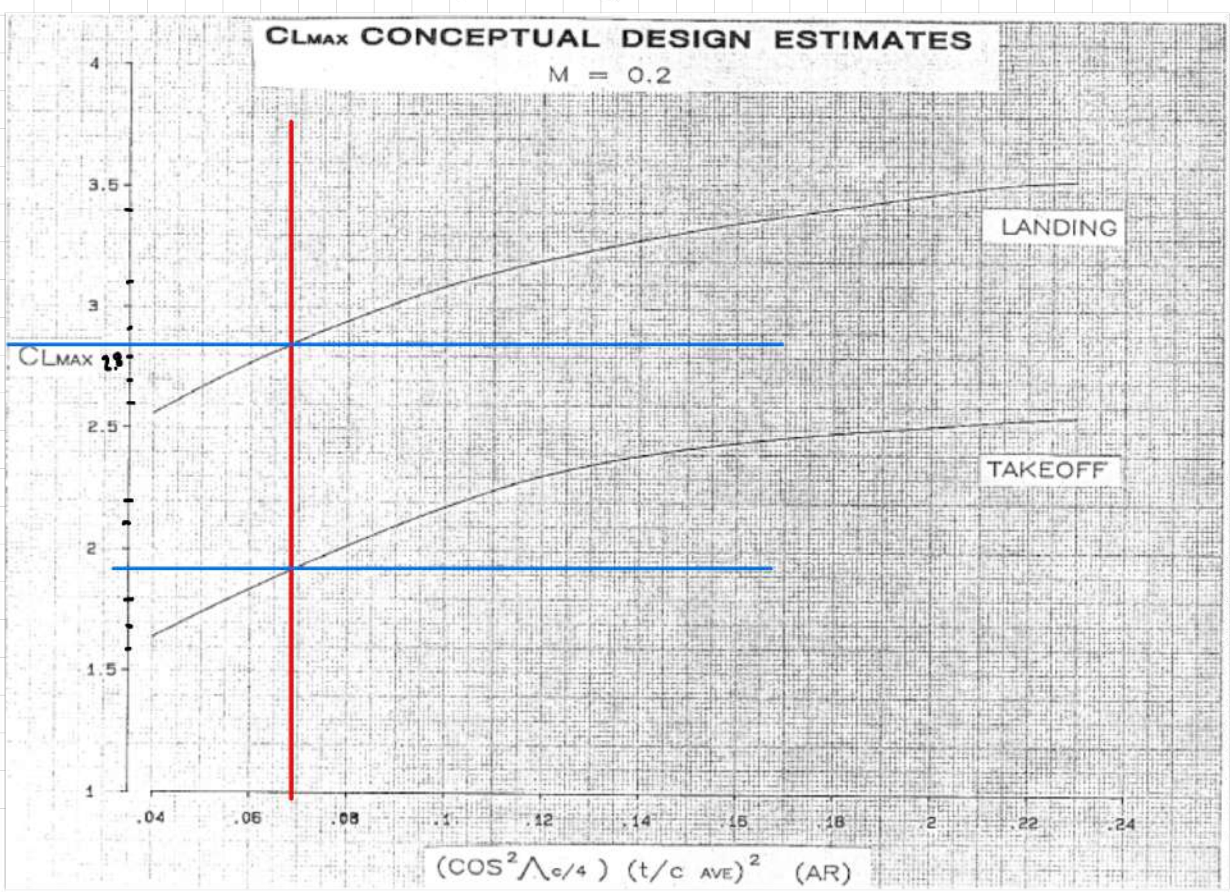
$t/c = 0.113$

⑤ $\cos^2\Lambda \, (t/c)^2 \, AR = \cos^2(35) \, (0.113)^2 \, 8 = 0.0685$

Figure 3

$C_{L\,max})_{LDG} = 2.85$

$C_{L\,max})_{T/O} = 1.9$



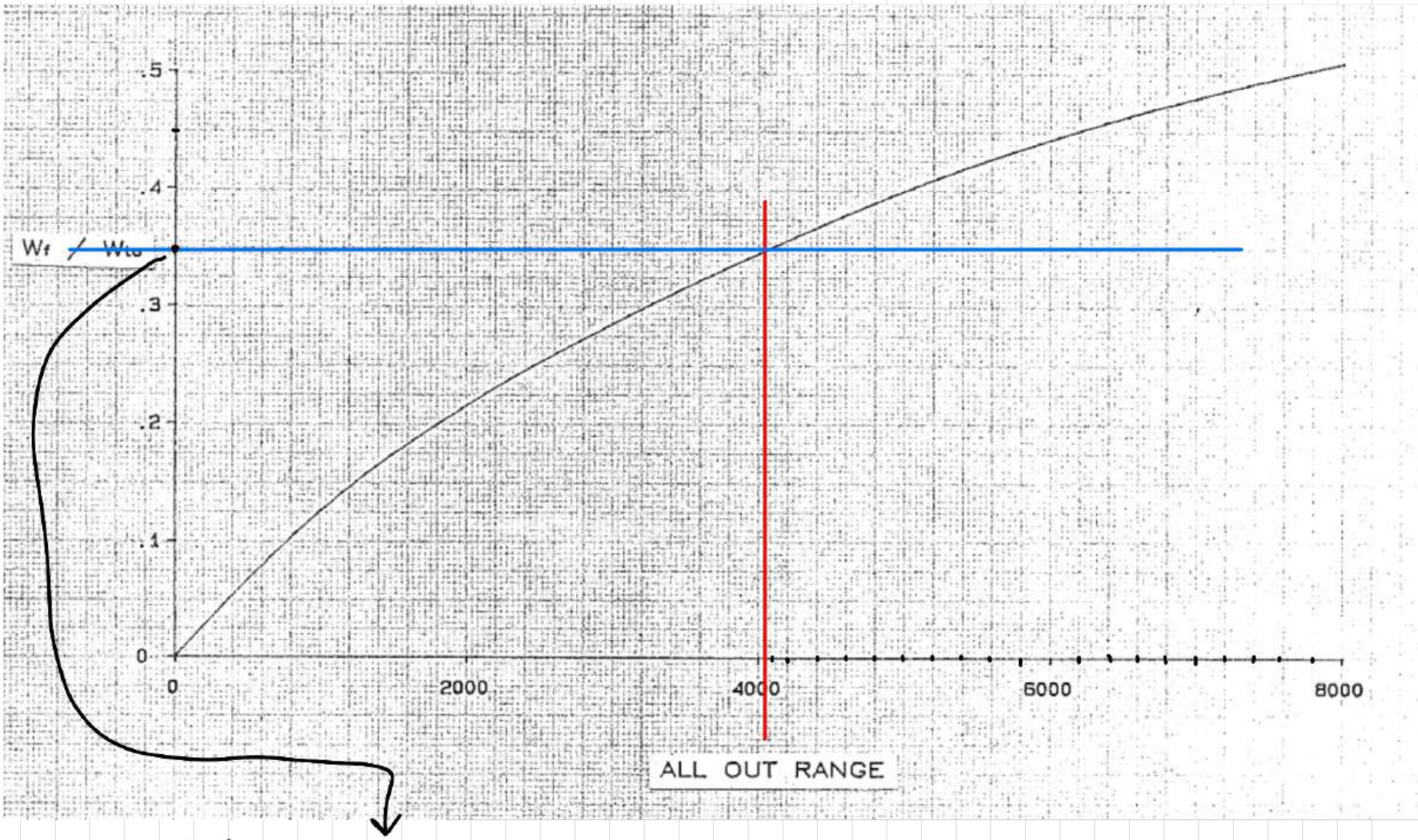
(6) $\left.\frac{W}{S}\right)_{LDG} = \left(\frac{V_{approach}}{1.3}\right)^2 \frac{\sigma \; C_{Lmax})_{LDG}}{296} = \left(\frac{135}{1.3}\right)^2 \frac{0.953 \times 2.85}{296} = 98.9525 \left[\#/ft^2\right]$

(7) $V_{cruise} = M\sqrt{\gamma R T} = 0.80 \times 576.4 = 461.12 \;[KTS]$

$R_{All\text{-}out} = R_{schedule} + R_{reserved} = R_{schedule} + 200 + 0.75\, V_{cruise}$

$= 3500 + 200 + 0.75 \times 461.12 = 4045.84 \;[Nmi]$

(8) From Figure 4



$\frac{W_f}{W_{T/O}} = 0.35$

(9) Engine tye JT9D

$\left.\frac{W_f}{W_{T/O}}\right)_{JT9D} = \left.\frac{W_f}{W_{T/O}}\right)_{JT8D} \times \frac{SFC)_{JT9D}}{SFC)_{JT8D}} = 0.35 \times \frac{0.61}{0.78} = 0.2737 \rightarrow \overset{+0.0257}{0.299}$

(10) $\left.\frac{W}{S}\right)_{T/O} = \frac{W/S)_{LDG}}{1 - X \cdot \frac{W_f}{W_{T/O}}} = \frac{98.9525}{1 - 75\% \times 0.299} = 127.5572 \;[\#/ft^2]$

(11) $\frac{W}{S}\Big)_{IC} = 0.965 \frac{W}{S}\Big)_{T/O} = 0.965 \times 127.5572 = 123.0927 \quad [\#/ft^2]$

(12) $C_L)_{IC} = \dfrac{W/S)_{IC}}{1481\ \delta\ M^2} = \dfrac{123.0927}{1481 \times 0.236 \times 0.80^2} = 0.5503 \neq C_L = 0.5$

Try $C_L = 0.55$

② $C_L = 0.55$

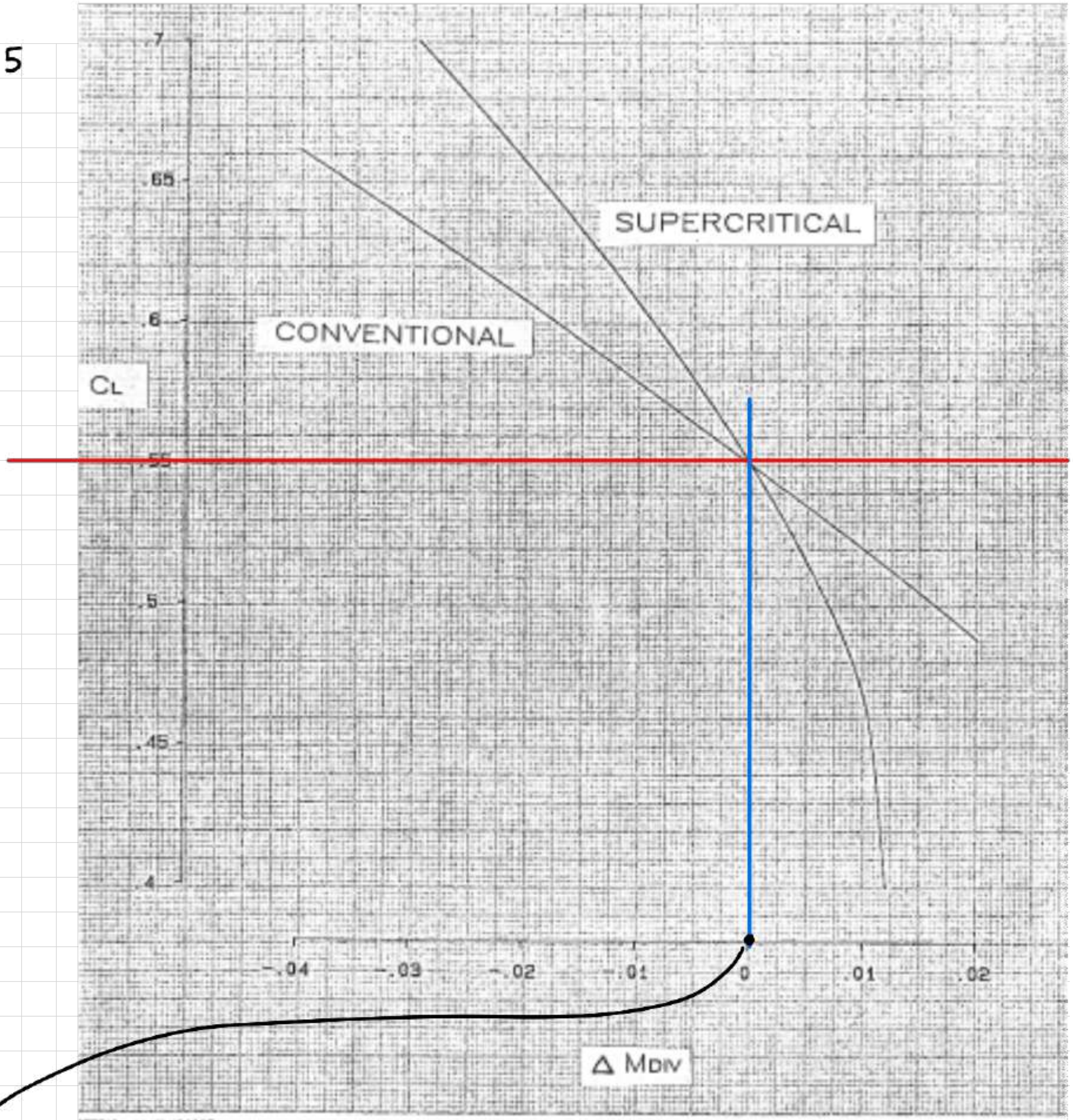


FIGURE 2

$\Delta M_{Div} = 0$

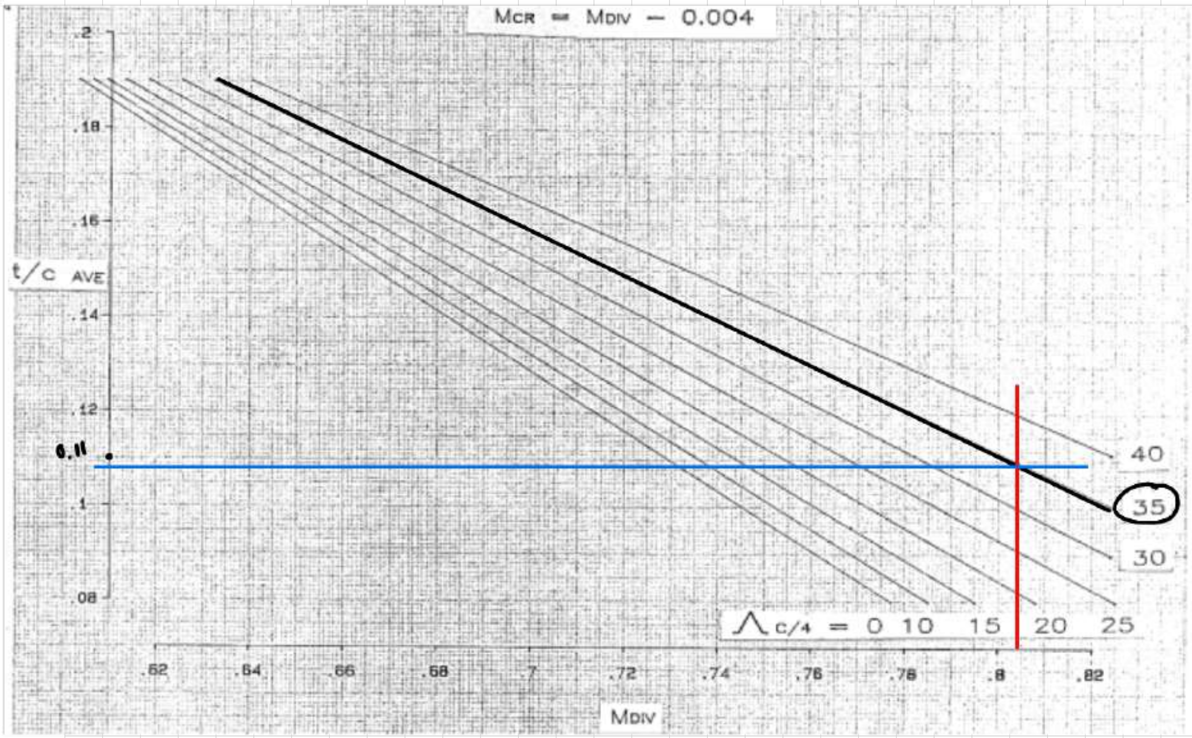
③ $M_{Div} = (M_{cruise} + 0.004) - \Delta M_{Div}$

$= (0.8 + 0.004) - 0$

$M_{Div} = 0.804$

(4) $\Lambda = 35^\circ$ $\quad M_{Div} = 0.804$

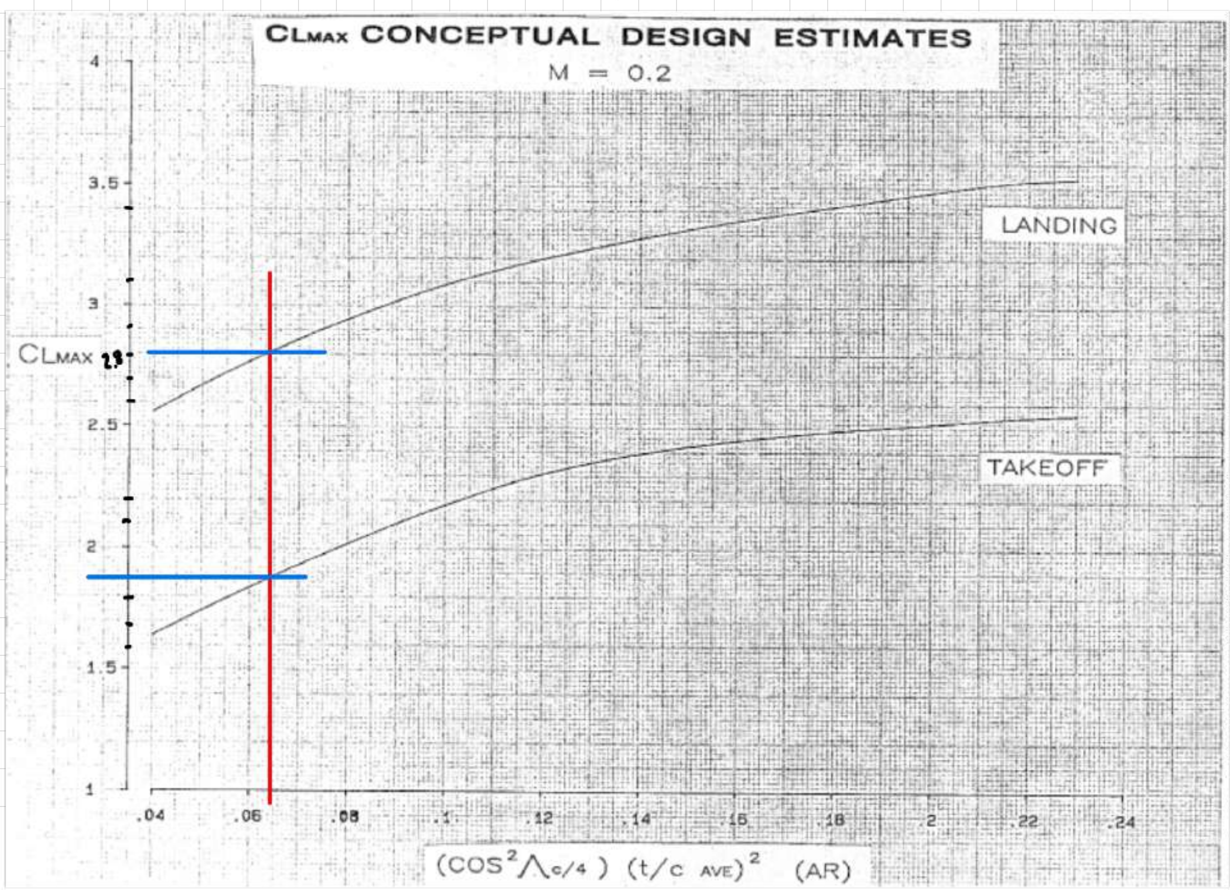
From Figure 1a



$t/c = 0.109$

(5) $\cos^2\Lambda \, (t/c)^2 \, AR = \cos^2(35) \, (0.109)^2 \, 8 = 0.064$

Figure 3



$C_{L_{max}})_{LDG} = 2.8$

$C_{L_{max}})_{T/O} = 1.88$

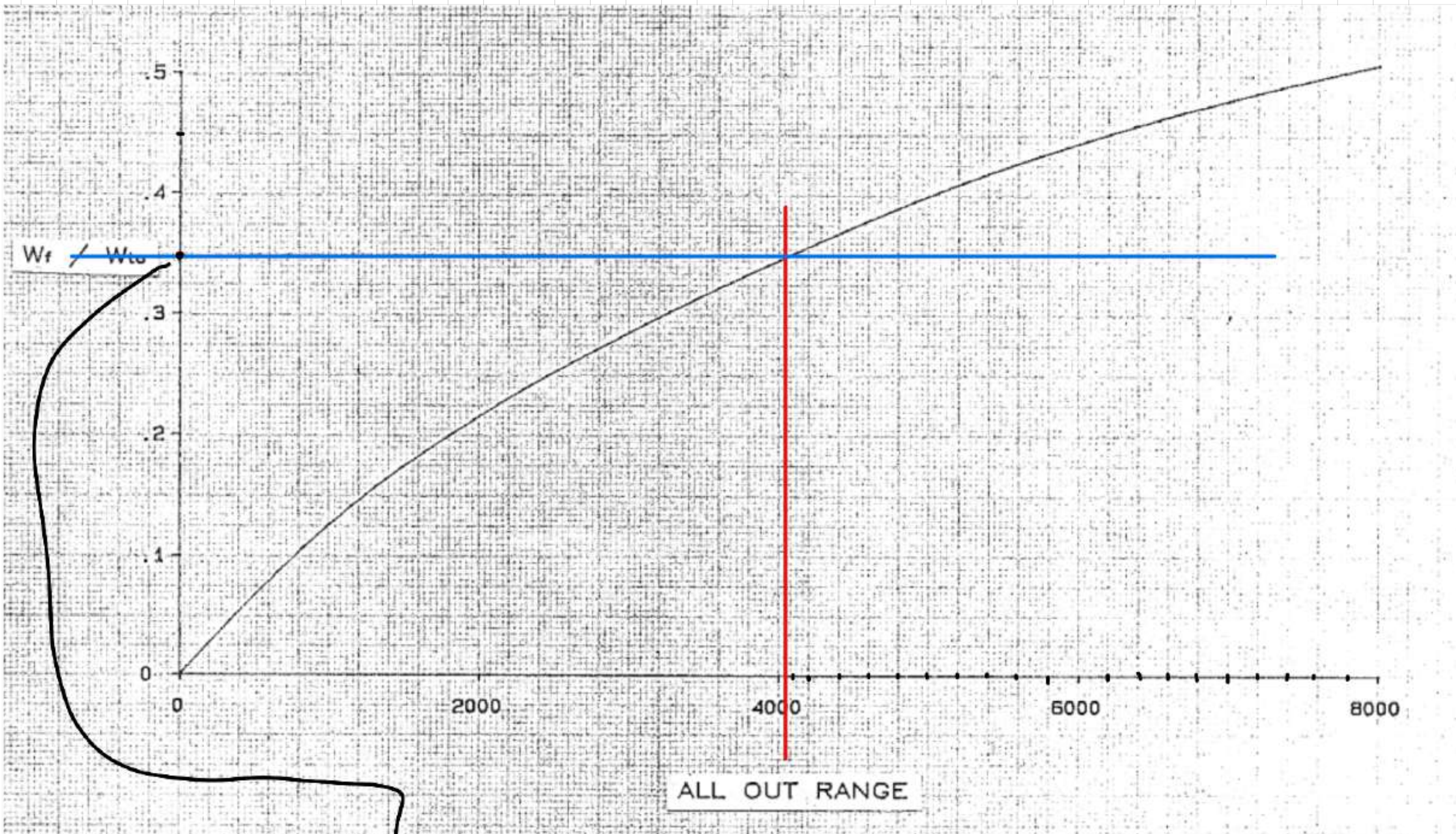
⑥ $\left.\frac{W}{S}\right)_{LDG} = \left(\frac{V_{approach}}{1.3}\right)^2 \frac{\sigma\ C_{Lmax})_{LDG}}{296} = \left(\frac{135}{1.3}\right)^2 \frac{0.953 \times 2.8}{296} = 97.22\ [\#/ft^2]$

⑦ $V_{cruise} = M\sqrt{\gamma R T} = 0.80 \times 576.4 = 461.12\ [KTS]$

$R_{All\text{-}out} = R_{schedule} + R_{reserved} = R_{schedule} + 200 + 0.75\, V_{cruise}$

$= 3500 + 200 + 0.75 \times 461.12 = 4045.84\ [Nmi]$

⑧ From Figure 4



$\frac{W_f}{W_{T/o}} = 0.35$

⑨ Engine tye JT9D

$\left.\frac{W_f}{W_{T/o}}\right)_{JT9D} = \left.\frac{W_f}{W_{T/o}}\right)_{JT8D} \times \frac{SFC)_{JT9D}}{SFC)_{JT8D}} = 0.35 \times \frac{0.61}{0.78} = 0.2737 \xrightarrow{+0.0257} 0.299$

⑩ $\left.\frac{W}{S}\right)_{T/O} = \frac{W/S)_{LDG}}{1 - X\cdot\frac{W_f}{W_{T/o}}} = \frac{97.22}{1 - 75\% \times 0.299} = 125.324\ [\#/ft^2]$

(11) $\left.\frac{W}{S}\right)_{IC} = 0.965 \left.\frac{W}{S}\right)_{T/O} = 0.965 \times 127.5572 = 120.94 \quad [\#/ft^2]$

(12) $\left.C_L\right)_{IC} = \dfrac{W/S)_{IC}}{1481\ \delta\ M^2} = \dfrac{120.94}{1481 \times 0.236 \times 0.80^2} = 0.54 \approx C_L = 0.55$

$\Downarrow$

$\boxed{C_L = 0.545}$

TAKE OFF FIELD LENGTH

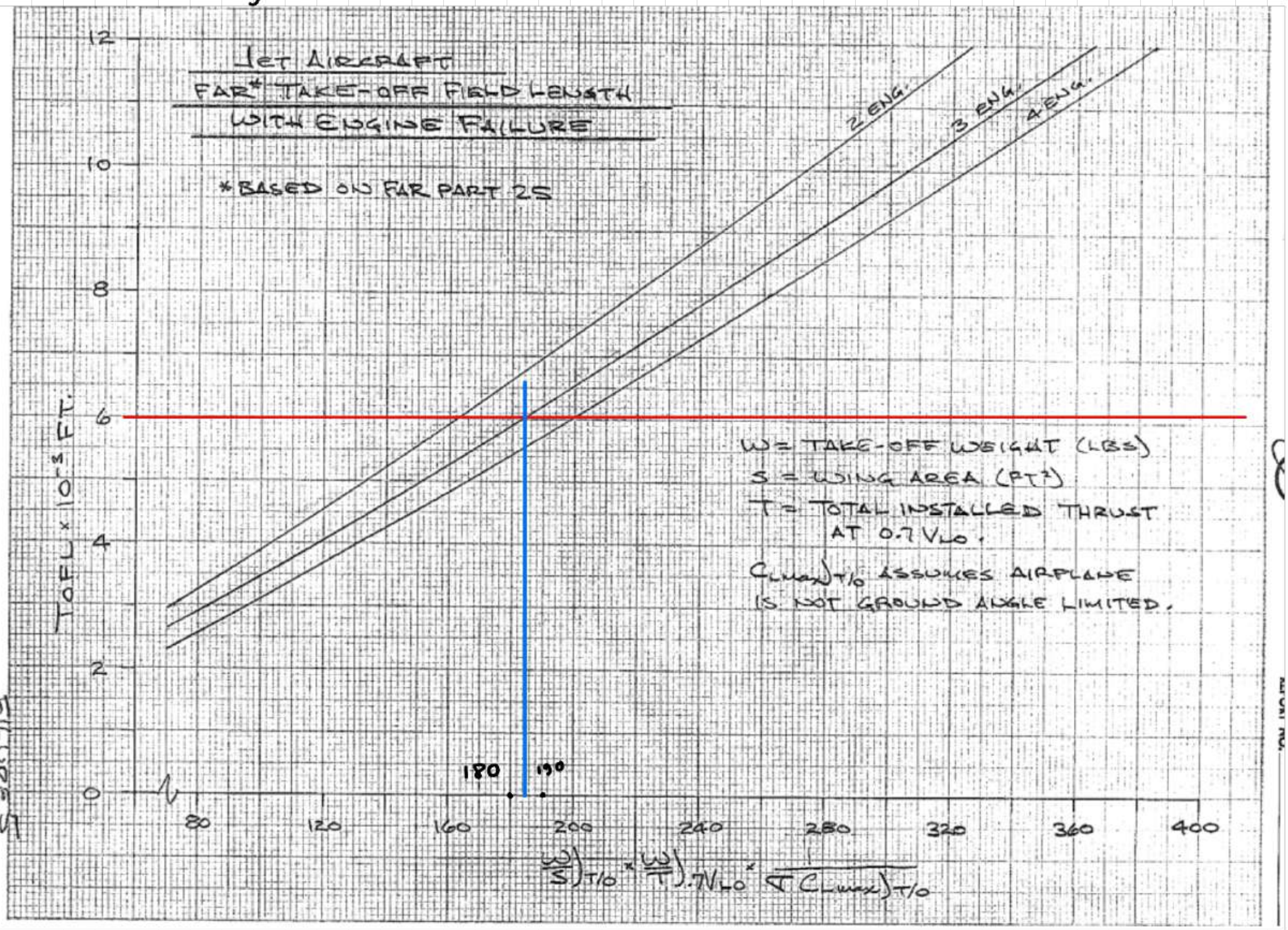
Design Specification:

Number of passengers (2-class, domestic rules)	210
Weight of cargo (10 pounds/ft^3)	8000 pounds
Range (still air)	3500 nautical miles
Takeoff field length (sea-level, hot day 84° f)	6000 feet
Landing approach speed	135 knots
Cruise Mach number	0.80
Initial cruise altitude	35,000 feet
Maximum wingspan	118 feet

TOFL

3 Engines TOFL = 6000 [ft]

From Figure 5



$$\frac{W}{S}\Big)_{T/O} \times \frac{W}{T}\Big)_{0.7V_{LO}} \times \frac{1}{\sigma \; C_{L_{max}})_{T/O}} = 184$$

$$\Rightarrow \quad \frac{W}{T}\Big)_{0.7V_{LO}} = 184 \; \frac{\sigma \; C_{L_{max}})_{T/O}}{\frac{W}{S}\Big)_{T/O}}$$

$$= 184 \; \frac{0.953 \times 1.88}{125.324}$$

$$= 2.63$$

$$V_{L/o} = 1.2\left[\frac{296 \; W/S)_{T/o}}{\sigma \; C_{Lmax\,T/o}}\right]^{0.5} = 1.2\left[\frac{296 \times 125.324}{0.953 \times 1.88}\right]^{0.5} = 172.67 [kTS]$$

$$M_{L/o} = \frac{V_{L/o}}{661 \times \sqrt{\sigma}} = \frac{172.67}{661 \times \sqrt{0.953}} = 0.2676$$

$$0.7\,M_{L/o} = 0.7 \times 0.2676 = 0.1873$$

From JT9D Chart at sea level:

TAKE-OFF RATING WITHOUT WATER INJECTION
Ambient Temperature 80° F

Static	T_{SLST} = 45500	1482
0.15	39120	1509
0.1873		
0.30	34820	1585
0.45	31750	1700

$$T_{M=0.2676} = 38050.7 \; \#$$

$$\frac{W}{T} = \frac{W}{T}\Big)_{0.7V_{L/o}} \times \frac{T_{M=0.2676}}{T_{SLST}} = 2.63 \times \frac{38050.7}{45\,500} = \boxed{2.2}$$

WEIGHT

LOOP

$$W_{wing} = \frac{0.00945\,(W_{T/O})^{1.195}\,(AR)^{0.8}\,(1+\lambda)^{0.25}}{(\bar{t}/c)^{0.4}\,(\cos\Lambda_{c/4})\left[(W/S)_{T/O}\right]^{0.695}}\,k_w\,\eta^{0.5}$$

constant, design, wing engine

$$= \frac{0.00945\,(W_{T/O})^{1.195}\,(8)^{0.8}\,(1+0.35)^{0.25}}{(0.109+0.03)^{0.4}\,\cos(35^\circ)\,(125.324)^{0.695}}\,1.01\times 3.75^{0.5}$$

constant

$$= 0.0098\,(W_{T/O})^{1.195}$$

$$W_{fuselage} = 0.6727\,k_f\,(W_{T/O})^{0.235}\,\ell^{0.6}\,d^{0.72}\,\eta^{0.3}$$ Constant

$$\ell = \left(3.76\times\frac{\#s\text{ of PAX}}{\#s\text{ of Seat Abreast}} + 33.2\right)1.1$$

design

$$= \left(3.76\times\frac{210}{8} + 33.2\right)1.1$$

$$= 145.09\ [ft]$$

design

$$d = (1.75\times\#s\text{ of Seat Abreast} + 1.58\times\#s\text{ of Aisles} + 1)\,1.1$$

$$= (1.75\times 8 + 1.58\times 2 + 1)\,1.1 = 19.976\ [ft]$$

Constant PAX>135

- $$W_{fuselage} = 0.6727\,k_f\,(W_{T/O})^{0.235}\,\ell^{0.6}\,d^{0.72}\,\eta^{0.3}$$

$$= 0.6727\times 11.5\times(W_{T/O})^{0.235}\,145.09^{0.6}\,19.976^{0.72}\,3.75^{0.3}$$

$$= 1968.2365\,(W_{T/O})^{0.235}$$

- $$W_{Landing\ Gear} = 0.040\times W_{T/O}$$

- $$W_{Nacelle+Pylon} = 0.0555\,T = \frac{0.0555\times W_{T/O}}{(W/T)} = \frac{0.0555}{2.2}\,W_{T/O} = 0.02523\,W_{T/O}$$

$$W_{Tail\ Surface} = K_{TS}\,W_{wing} = \left(0.17+\frac{0.08}{3}\right)W_{wing} = 0.1967\,W_{wing}$$

0.17 wing engine

0.25 fuselage engine

- $$W_{TS+wing} = W_{Tail\ Surface} + W_{wing} = 0.1967\,W_{wing} + W_{wing} = 1.1967\,W_{wing}$$

$$= 1.1967\times 0.0098\,(W_{T/O})^{1.195} = 0.0117\,(W_{T/O})^{1.195}$$

- $W_{Power\ Plant} = \dfrac{W_{T/O}}{3.58\ W/T} = \dfrac{1}{3.58 \times 2.2} W_{T/O} = 0.12697\ W_{T/O}$

- $W_{fuel} = 1.0275 \times \dfrac{W_{fuel}}{W_{T/O}} \times W_{T/O} = 1.0275 \times 0.35 \times W_{T/O}$

$= 0.359625\ W_{T/O}$

- $W_{Payload} = 215\ PAX + W_{cargo} = 215 \times 210 + 8000 = 53150\ \#$

- $W_{fixed\ equipment} = 132\ PAX + 300\ \#s$ of engine $+ 0.035\ W_{T/O}$

$+ 260\ N_{Flight\ Crew} + 170\ N_{Cabin\ attendants}$

$= 132 \times 210 + 300 \times 3 + 0.035 \times W_{T/O}$

$+ 260 \times 2 + 170 \times 6 = 30160 + 0.035\ W_{T/O}$

$$W_{TS+wing} + W_{fuselage} + W_{Landing\ Gear} + W_{Nacelle + Pylon} + W_{Power\ Plant} + W_{fuel} + W_{Payload} + W_{fixed\ equipment} = W_{T/O}$$

$$0.0098 (W_{T/O})^{1.195} + 1968.2365 (W_{T/O})^{0.235} + 0.040 \times W_{T/O} + 0.02523\ W_{T/O} + 0.12697\ W_{T/O} + 0.359625\ W_{T/O} + 53150 + 30160 + 0.035\ W_{T/O} - W_{T/O} = 0$$

$$0.0117 (W_{T/O})^{1.195} + 1968.2365 (W_{T/O})^{0.235} - 0.413175\ W_{T/O} + 83310 = 0$$

$\Rightarrow W_{T/O} = 477897\ \#$

$S_{REF} = \dfrac{W_{T/O}}{WL_{T/O}} = \dfrac{477897}{125} = 3873\ [ft^2]$

$AR = \dfrac{b^2}{S_{REF}} \Rightarrow b = \sqrt{AR\ S_{REF}} = \sqrt{8 \times 3873} = 176\ [ft]$

$$\text{M.A.C.} = \frac{S_{REF}}{b} = \frac{3873}{176} = 22 \quad [ft]$$

$$\text{Thrust} = \frac{W_{T/O}}{W/T} = \frac{477897}{2.2} = 217226 \quad \#$$

$$\text{Thrust per engine} = \frac{\text{Thrust}}{\#\text{s of engine}} = \frac{217226}{3} = 72408.6 \quad \#$$

DRAG

This section works with assumption $M = 0.5$ & $h = 20,000$ [ft]

Reynolds number over characteristic length:

$$\frac{Re}{\ell} = \frac{\rho V_{M=0.5}}{\mu} = 1.426 \times 10^6 \left[\frac{1}{ft}\right]$$

Parasite drag

WING:

$$\boxed{\begin{aligned} b &= 176 \text{ [ft]} \\ S_{REF} &= 3873 \text{ [ft}^2\text{]} \\ t/c &= 0.1 \quad [1] \\ \Lambda &= 35° \\ \lambda &= 0.35 \\ MAC &= 22 \text{ [ft]} \end{aligned}}$$

Reynolds number:

$$Re = 1.426 \times 10^6 \, MAC = 1.426 \times 10^6 \times 22 = 31372000 \; [1] \qquad [1]$$

Friction coefficient:

Figure 11.2 $\Longrightarrow$ $c_f = 0.002765$

Form factor:

Figure 11.3 $\Longrightarrow$ $K = 1.19$

Wetted area:

$$S_{wet} = 2\,(S_{ref} - 20 \times 30)\,1.02 = 2\,(3873 - 20 \times 30)\,1.02 = 6677 \text{ [ft}^2\text{]}$$

Drag area:

$$f = K \, C_f \, S_{wet} = 21.05 \text{ [ft}^2\text{]}$$

FUSELAGE

$$\boxed{\begin{aligned} L &= 179\ [ft] \\ D &= 20\ [ft] \\ S_{wet} &= 10122\ [ft^2] \end{aligned}}$$

Reynolds number:

$$Re = 1.426 \times 10^6\ L = 255254000\ [1]$$

Friction coefficient:

Figure 11.2 $\Rightarrow$ $C_f = 0.00183$

Form factor:

$L/D = 8.36$ & Figure 11.4 $\Rightarrow$ $K = 1.1135$

Drag area

$$f = K\ C_f\ S_{wet} = 20.635\ [ft^2]$$

OTHER

Tail Surface:

$$f = 0.38\ f_{wing} = 8\ [ft^2]$$

Nacelle:

$$f = 1.25 \times C_{f\,wing} \times S_{wet\ nacelle} = 5.87\ [ft^2]$$

Pylon:

$$f = 0.2 \times f_{nacelle} = 1.174\ [ft^2]$$

TOTAL

$$f_{total} = \Sigma f = 60.133 \, [ft^2]$$

$$C_{D_p} = \frac{f}{S_{ref}} = 0.0161$$

$$e = \frac{1}{1.035 + 0.38 \, C_{D_p} \pi AR} = 0.84$$

CLIMB

$$W_{climb} = \frac{1+0.965}{2} W_{T/O} = 464722.5 \,[lb]$$

$$V_{(L/D)_{max}} = \frac{12.9}{(f e)^{1/4}} \left(\frac{W}{\sigma b}\right)^{1/2} = 332.11$$

$$V_{climb} = 1.3 \, V_{(L/D)_{max}} = 431.744 \, KTS \Rightarrow M = 0.749$$

$$T_r = Drag = \frac{\sigma f v^2}{296} + \frac{94.1}{\sigma e}\left(W/b\right)^2 \frac{1}{v^2}$$
$$= 29196.7 \,[lb]$$

$$T_a)_{JT9D} = 15400 \text{ lb}, \quad M = 0.65 \text{ at } 20\,000 \,[\cancel{ft}]$$

$$T_a = \frac{\text{Thrust per engine}}{\text{Thrust sea level static}} \times T_a)_{JT9D} = 24604.23 \,[lb]$$

$$R/C = 101 \frac{T_a - T_r}{W} V = 4186.44$$

$$Time_{climb} = \text{Initial cruise altitude} / R/C = 8.36 \,[hr]$$

$$Range_{climb} = V_{climb} \times Time = 60.1586 \,[nmi]$$

$$W_{fuel\ climb} = N_{engine} \times T_a \times M \times Time / 60$$
$$= 6685.73 \,[lb]$$

RANGE
LOOP

These sections are in range loop:

C_L LOOP

TAKE OFF FIELD LENGTH

WEIGHT LOOP

DRAG

CLIMB

Next section in Range loop

RANGE

$W_0 = W_{t/o} - W_f)_{CL} = 327000 - 5717 = 321283 \text{ lb}$

$W_1 = (1 - W_f / W_{t/o})\ W_{t/o} = (1 - 0.3)\ 342000 = 239206$

$$C_L)_{Average} = \frac{(W_0 + W_1)/2\, S_{REF}}{1481 \times 0.236 \times M^2} = 0.474$$

$$C_{Di} = \frac{C_L)_{AVG}^2}{pi\ AR\ e} = 0.010815$$

0.001

$$C_{D\,total} = C_{DP} + C_{Di} + \Delta C_{DC} = 0.030152$$

$$\frac{L}{D} = \frac{C_L)_{Average}}{C_{D\,total}} = 0.030152$$

$$T_r = \frac{W_0 + W_1}{2} \div \frac{L}{D} = 18321.4$$

$$T_r)_{JT9D} = T_r \times \frac{T_{JT9D\ sea\ level\ static}}{T_{per\ engine}} = 5267 \text{ lb}$$

At 35K $\quad M = 0.8$

Specific fuel Consumption, SFC, $c = 0.6145$

$$R_{cruise} = \frac{V}{c}\frac{L}{D} \ln\left(\frac{W_0}{W_1}\right) = 3885.37 \text{ (nmi)}$$

$$R = R_{cruise} + R_{climb} = 3885 + 84.6 = 3970 \text{ (nmi)}$$

Finished Range loop! Vary Weight fuel takeoff step 8 in C_L loop to get Correct Range

CLIMB

PERFORM

-ANCE

TOP CLIMB

$$C_{L_{IC}} = \frac{W_0/S_{REF}}{1481 \times 0.2362 \times M^2} = 0.5578$$

$$C_{D_i} = \frac{{}^{2}}{\pi AR\, e} = 0.01525$$

$$C_D = C_{D_i} + C_{D_p} + \Delta C_{D_c} = 0.03689$$

$$\frac{L}{D} = \frac{C_L}{C_D} = 15.1$$

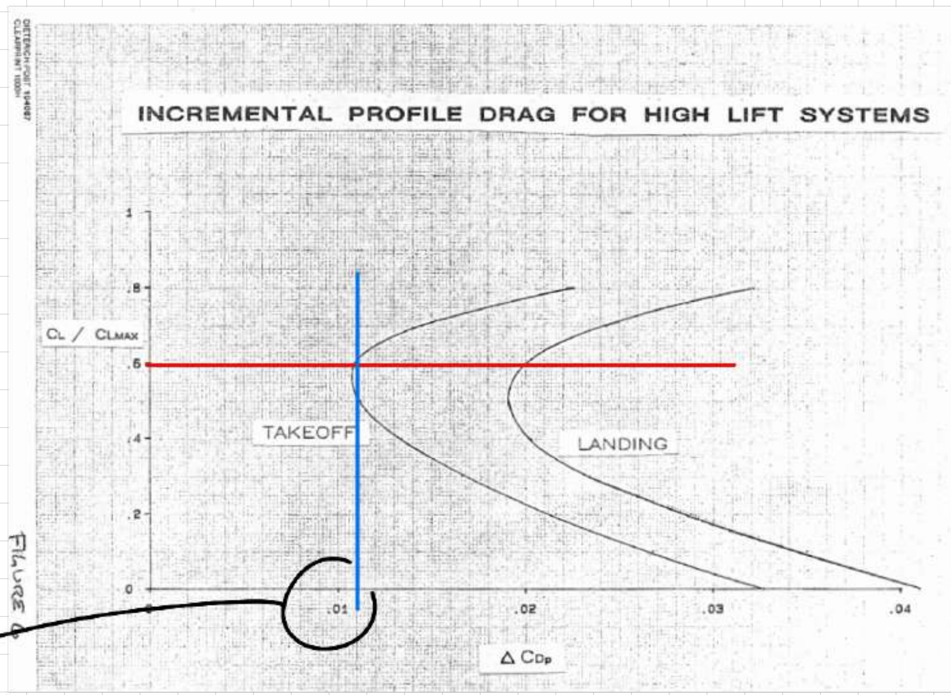
$$T_r = \frac{W_0}{L/D} \div \#\text{ of engines} = 5668.66\ \text{lb}$$

$$T_r)_{JT9D} = T_r \times \frac{T_{\text{sea level static}}}{T_{\text{per engine}}} = 7232.1 < 10\,000 \checkmark$$

Segment 1

$$C_{L\,takeoff} = \frac{C_{L\,max\,takeoff}}{1.2^2} = 1.296$$

$$\frac{C_{L\,takeoff}}{C_{L\,max\,takeoff}} = 0.592$$



$$\Delta C_{Dp} = 0.014$$

$$C_{Di} = \frac{C_L^2}{\pi AR\, e} = 0.08233$$

$$C_D = C_{Dp} + \Delta C_{Dp} + \Delta C_{D\,gear} + C_{Di}$$

$$C_D = 0.131466$$

$$\frac{L}{D} = \frac{C_L}{C_D} = 9.857$$

$$T_r = \frac{W_{Take\ off}}{L/D} = 26580 \text{ lb}$$

$$\frac{T_a}{N_{engine}} = \frac{T_{per\ engine}}{T_{sea\ level\ static}} \times T_{Max\ limit\ operating\ dry\ take\ off}$$

$$= 27641.186 \text{ lb}$$

$$\text{Gradient} = \frac{(\#s\ of\ engine - 1) \times \frac{T_a}{N_{engine}} - T_r}{W_{take\ off}} \times 100\%$$

$$= 10.955\ \%$$

Segment 2

$$C_D = C_{Dp} + \Delta C_{Dp} + C_{Di} = 0.117$$

$$\frac{L}{D} = \frac{C_L^{\leftarrow \text{seg } 1}}{C_D} = 11.07$$

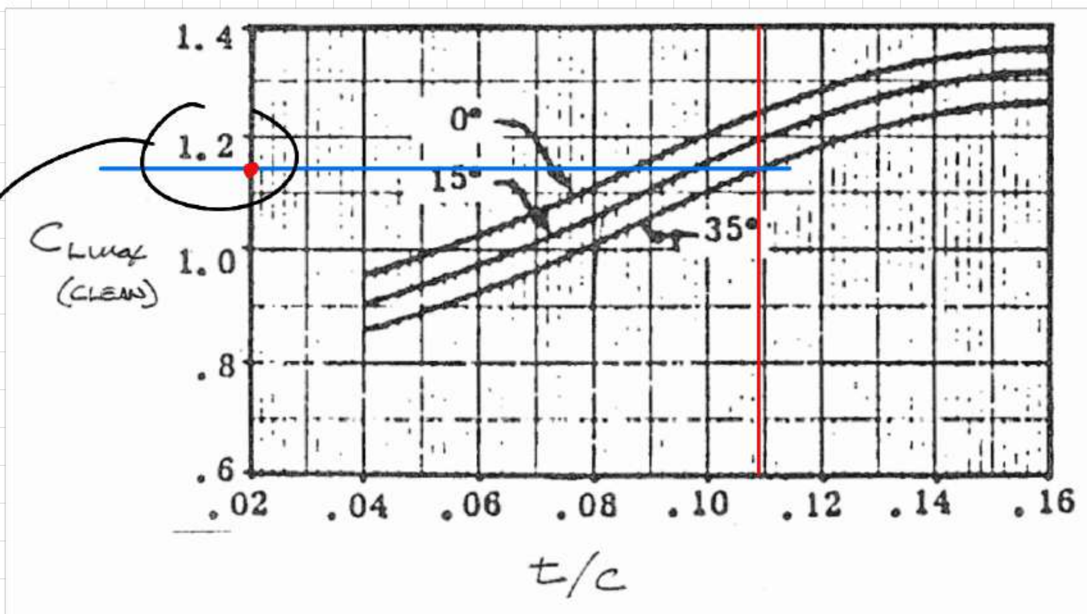
$$T_r = W_{Take\ off} / (L/D) = 23648 \text{ lb}$$

$$\text{Gradient} = \frac{(\#\text{s of engine} - 1) \times \left(\frac{T_a}{N_{engine}}\right)^{seg\,1} - T_r^{\leftarrow seg\,2}}{W_{take\,off}} \times 100\%$$

$$= 12.674\%$$

Segment 3

$t/c = 0.108 \quad \Lambda = 35°$



$C_{Lmax})_{clean} = 1.14467$

$$V = 1.2\sqrt{\frac{296 \times \frac{W}{S})_{take\,off}}{6.9204 \times C_L}} = 226.8 \text{ KTS}$$

$$M = \frac{V}{c} = \frac{226.8}{659} = 0.344$$

$$C_L = \frac{C_{L\max})_{clean}}{(1.2)^{\wedge 2}} = 0.795$$

$$C_D = C_{Dp} + \frac{C_L^2}{\pi A\!\!R\, e} = 0.0516$$

$$\frac{L}{D} = \frac{C_L}{C_D} = 15.4$$

$$T_r = \frac{W_{TO}}{L/D} = 17011.6 \text{ lb}$$

$$T_{JT9D\ Mx\ climb\ condition} = 27318 \text{ lb}$$

$$\frac{T_a}{\#\text{s of engine}} = \frac{T_{per\ engine}}{T_{sea\ level\ stic}} \times 27318 = 21412.4 \text{ lb}$$

$$\text{Gradient} = \frac{(\#\text{s of engine} - 1) \times \frac{T_a}{N_{\text{engine}}} - T_r}{W_{\text{take off}}} \times 100\%$$

Segment 3

$$= 9.85\%$$

APPROACH

$$C_L)_{\text{approach}} = \frac{C_{L\,max\,take\,off}}{1.3^2} = 1.1$$

$$\frac{C_{L\,approach}}{C_{L\,max\,T/O}} = 0.5917 \Longrightarrow \Delta C_p = 0.01083$$

$$C_D = C_{Dp} + \Delta C_{Dp} + \frac{C_L^2}{\pi AR e} = 0.189$$

$$\frac{L}{D} = \frac{C_L}{C_D} = 12.1$$

$$W_{\text{Landing}} = \frac{W}{S}\Big)_{\text{landing}} \times S_{REF} = 199865\ lb$$

$$T_r = \frac{W_{landing}}{L/D} = 16514.5 \text{ lb}$$

$$V = \sqrt{\frac{296 \left.\frac{W}{S}\right)_{landing}}{0.953 \times C_L)_{approach}}} = 165.2 \text{ kTS}$$

$$M = \frac{V}{\text{sound velocity}} = \frac{V}{667} = 0.2476$$

$$\to T_{JT9D} \text{ Max climb condition} = 29492.3 \text{ lb}$$

$$\frac{T_a}{\#\text{s of engines}} = \frac{T_{per\ engine}}{T_{sea\ level}} \times \checkmark = 23116.67 \text{ lb}$$

$$\text{Gradient} = \frac{\left(\#\text{s of engines} - 1\right) \times \frac{T_a}{N_{engine}} - T_r}{W_{take\ off}} \times 100\%$$

$$= 14.87\ \%$$

LANDING

$$C_L = \frac{C_{L\,max\ landing}}{(1.3)^2} = 1.653$$

$$\frac{C_{L\,landing}}{C_{L\,max\ landing}} = 0.592 \Rightarrow \Delta C_{Dp} = 0.02$$

$$C_D = C_{Dp} + \Delta C_{Dp} + \Delta C_{D\,gear} + \frac{C_L^2}{\pi A\!\!R\, e}$$

$$= 0.189$$

$$\frac{L}{D} = \frac{C_L}{C_D} = 8.74$$

Same value in approach section

$$T_r = \frac{W_{Landing}}{\frac{L}{D}} = 22856.77 \text{ lb}$$

given in specs

$$M = \frac{V}{C} = \frac{V}{667} = 0.2024$$

$$T_{JT9D\ M_{landing\ Dry}} = 37310.85 \text{ lb}$$

$$\frac{T_a}{\#s\ of\ engine} = \frac{T_{per\ engine}}{T_{sea\ level\ static}} \times \sigma = 29245\ lb$$

$$Gradient = \frac{\#s\ of\ engine \times \frac{T_a}{N_{engine}} - T_r}{W_{take\ off}} \times 100\%$$

$$= 32.46\ \%$$

DIRECT OPERATING COST

Block velocity

$D = 1.15 \times R = 4025$ nmi

$T_{gm} = 0.25$ hr $\quad T_{CL} = 0.1D \quad T_D = 0 \quad T_{am} = 0.1$

$$T_{cruise} = \frac{D + k_a + 20 - D_{CL}}{V_{cr}} = 7.6 \text{ hr}$$

$$V_b = \frac{D}{\Sigma Time} = 493.6 \text{ mph}$$

Block time

$T_B = 13.33$ hr

Block fuel

$F_{CL} = W_{fuel\ climb} = 4855$ lb

$F_{cr} + F_{AM} = T_r)_{range} \times C_{at\ 35k} \times T_{cruise} = 72010$

$$F_B = (F_{cr} + F_{AM}) + F_{CL} = 76865 \text{ lb}$$

Fly operating cost

ⓐ Flight Crew

$$Payload = \frac{W_{payload}}{2000} = 26.575$$

$$\frac{\text{Cost}}{\text{block-hour}} = 17.849 \times \left(V \times \frac{W_{takeoff}}{10^5} \right)^{0.3} + 40.83 = 1973$$

$$\frac{\text{Cost}_{\text{flight-crew}}}{\text{ton-mile}} = \frac{\qquad}{V_{Block} \times \text{Payload}} = 0.015$$

(b) Fuel & oil

$$\frac{\text{Cost}_{\text{fuel+oil}}}{\text{ton-mile}} = \frac{1.02\, F_B\, C_F + N_e C_{OT} \times T_B \times 0.135}{D \times P}$$

$$= 0.0458$$

(c) Hull Insurance

$$W_a = W_{TO} - W_{fuel} - W_{PL} - W_{PP}$$

$$= 93839.2 \text{ lb}$$

$$C_a = 2.4 \times 10^6 + 87.5\, W_a = \$10610928.7$$

$$C_e = 590\,000 + 16\, T_e = \$1160621.868$$

$$C_T = C_a + N_e\, C_e = \$14092754$$

$$U = 630 + \frac{4000}{1 + \frac{1}{T_B + 0.5}} = 4215.68$$

$$C_{T\ \text{insurance}} = \frac{IRA \times C_T}{U\ V_B\ P} = \$0.0025485 / \text{ton-mile}$$

(d) Direc maintenance

a. Air-frame — Labor

$$K_{FHa} = 4.9169 \log_{10}\left(\frac{W_a}{10^3}\right) - 6.425 = 3.273$$

$$K_{FCa} = 0.21256\left[\log_{10}\left(\frac{W_a}{10^3}\right)\right]^{3.7375} = 2.6$$

$$T_F = T_B - T_{gm} = 7.9\ hr$$

$$R_L = \$8.6$$

$$C_{Tm} = \frac{K_{FHa} \times T_F + K_{FCa}}{V_B\ T_B\ P} \times R_L = \frac{\$0.002}{\text{ton-mile}}$$

b. Airframe — Matrial

$$K_{FHa} = 1.5994 \times \frac{C_a}{10^6} + 3.4263 = 20.4$$

$$K_{FCa} = 1.922 \times \frac{C_a}{10^6} + 2.2504 = 22.6$$

$$C_{Tm} = \frac{K_{FHa} \times T_F + K_{FCa}}{V_B\ T_B\ P} = \frac{\$0.00172}{\text{ton-mile}}$$

c. Einge - labor

$$K_{FH_e} = \frac{N_e(T_e/10^3)}{0.82715\frac{T_e}{10^3} + 13.639} = 2.48$$

$$K_{FC_e} = 0.2 \times N_e = 0.6$$

$$T_F = T_B - T_{gm} = 7.9\ hr$$

$$R_L = \$8.6$$

$$C_{Tm} = \frac{K_{FH_e} \times T_F + K_{FC_e}}{V_B\ T_B\ P} \times R_L = \frac{\$0.002}{\text{ton-mile}}$$

$$= \$0.00162 / \text{ton-mile}$$

d. Engine - Material

$$K_{FH} = \left(28.23 \times \frac{C_e}{10^6} - 6.57\right) N_e = 78.75$$

$$K_{FC_e} = \left(3.66 \times \frac{C_e}{10^6} - 1.36\right) N_e = 16.88$$

$$C_{Tm} = \frac{K_{FH_e} \times T_F + K_{FC_e}}{V_B\ T_B\ P} = \frac{\$0.00597}{\text{ton-mile}}$$

e. Total

$$C_{Tm} = \Sigma(a+b+c+d) \times 2 = \frac{\$0.02323}{\text{ton mile}}$$

(e) Depreciation

$$C_{Tm} = \frac{1}{V_B \times P}\left(\frac{C_T + 0.6(C_T - N_e C_e) + 0.3 N_e C_e}{D_a V}\right)$$

$$= \frac{\$\,0.026375}{\text{ton - mile}}$$

Total DOC

$$DOC = \sum\left(a + b + c + d + e\right)$$

$$= \frac{\$0.107078}{\text{ton - mile}}$$

$$\times \frac{\text{Payload}}{PAX} = \frac{\$0.01355}{PAX \times \text{mile}}$$