Marc Rozman

Aircraft Flight Mechanics

Project 2 - Chapter 4, Problem 36

11/10/17

Contents

Method

For each phase, time (Δt), cumulative time ($\Sigma\Delta t$), Minimum fuel required (ΔW_f), and wing loading $\left(\frac{W}{S}\right)$ are to be found.

Phase 1: Taxi

Given:

Phase time, height, thrust

$$\Delta t_1\ , h, T$$

Find:

Thrust specific fuel consumption:

$$c = \frac{\frac{dW_f}{dt}}{T}$$

Rearrange to find Fuel used during phase for constant thrust:

$$\Delta W_{f1} = cT\Delta t$$

Weight at the end of phase 1:

$$W_1 = \mathrm{W} - \Delta W_{f1}$$

Wing loading:

$$\frac{W_1}{S}$$

Phase 2: Take-off

<u>Given:</u>

height, h

<u>Find:</u>

Lift-off velocity:

$$V_{LO} = 1.2V_s = \sqrt{\frac{2.88(W/S)}{\rho_{SL}\sigma C_{Lmax}}}$$

Phase 2 time:

$$\Delta t_2 = \frac{V}{g\sigma(T_{max}/W)}$$

Cumulative time:

$$\Sigma\Delta t = \Delta t_1 + \Delta t_2$$

Thrust is constant, so:

$$\Delta W_{f2} = cT\Delta t$$

Weight at the end of phase 2:

$$W_2 = W_1 - \Delta W_{f2}$$

Wing Loading:

$$\frac{W_2}{S}$$

Phase 3: Climb

Given:

Initial height, final height, thrust

$$h_1, h_2, T$$

Density ratios at h1 and h2 to sea level

$$\sigma_1, \sigma_2$$

Find:

Fastest Climb:

Maximum aerodynamic efficiency (Lift/Drag):

$$E_m = \frac{1}{2\sqrt{KC_{D0}}}$$

Γ at final height, , h_2:

$$\Gamma_2 = 1 + \sqrt{1 + \frac{3}{[E_m \sigma_2 (T/W)_{SL}]^2}}$$

Fastest climb airspeed at final height, h_2:

$$V = V_2 = V_{FC} \; at \; h_2 = \sqrt{\frac{(T/S)\Gamma_2}{3\rho_{SL} C_{D0}}}$$

Constant throttle setting climb:

Time of fastest climb:

$$\Delta t_3 = \Delta t_{FC} \; \frac{23800}{(T/W)_{SL}} \sqrt{\frac{27\rho_{SL} C_{D0}}{8(T/S)_{SL}}} \left(e^{h2/23800} - e^{h1/23800}\right)$$

Cumulative time:

$$\Sigma\Delta t = \Delta t_1 + \Delta t_2 + \Delta t_3$$

Fuel used during fastest climb:

$$\Delta W_{f3} = W_2\left[1 - e^{\left\{\frac{-c}{3600}\sqrt{\frac{27\rho_{SL}C_{D0}}{8(T/S)_{SL}}}(h2 - h1)\right\}}\right]$$

Weight at the end of phase 3:

$$W_3 = W_2 - \Delta W_{f3}$$

Wing Loading:

$$\frac{W_3}{S}$$

Phase 4: Cruise

Given:

height, range

$$h, X$$

Density ratio at h to sea level

$$\sigma$$

Find:

Constant altitude-constant airspeed flight:

Best range cruise velocity:

$$V = V_{br} = \left[\sqrt{\frac{2(W/S)}{\rho_{SL}\sigma}}\right]\left[\sqrt[4]{\frac{3K}{C_{DO}}}\right]$$

Cruise time:

$$\Delta t_4 = \frac{X}{V}$$

Cumulative time:

$$\Sigma\Delta t = \Delta t_1 + \Delta t_2 + \Delta t_3 + \Delta t_4$$

Lift coefficient, drag coefficient and efficiency at start of cruise:

$$C_{L1} = \frac{2(W/S)}{\rho_{SL}\sigma V^2}$$

$$C_{D1} = C_{D0} + KC_L{}^2$$

$$E_1 = \frac{C_{L1}}{C_{D1}}$$

Using range equation for constant altitude-constant airspeed flight, solve for weight ratio and find fuel used:

$$X_{h,V} = \frac{2E_m V}{c} \arctan\left[\frac{\zeta E_1}{2E_m(1 - KC_{L_1}E_1\zeta)}\right]$$

$$\zeta = \frac{\Delta W_f}{W}$$

$$\Delta W_{f4} = W\left[\frac{\frac{2E_m}{E_1}tan\left(\frac{cX}{2E_mV}\right)}{1+\frac{2E_m}{E_1}tan\left(\frac{cX}{2E_mV}\right)KC_{L1}E_1}\right]$$

Weight at the end of phase 4:

$$W_4 = W_3 - \Delta W_{f4}$$

Wing Loading:

$$\frac{W_4}{S}$$

Phase 5: Descent

<u>Given:</u>

Initial height, final height,

$$h1, h2$$

Density ratios at h1 and h2 to sea level

$$\sigma_1, \sigma_2$$

<u>Find:</u>

Assume unpowered flight:

Best range airspeed during descent is airspeed at minimum drag:

$$V = V_{br} = V_{md} = \left[\sqrt{\frac{2(W/S)}{\rho_{SL}\sigma}}\right]\left[\sqrt[4]{\frac{K}{C_{DO}}}\right]$$

Time for best range unpowered descend:

$$\Delta t_5 = \frac{47600E_m}{V_{br,SL}}\left(e^{-h2/47600} - e^{-h1/47600}\right)$$

Cumulative time:

$$\Sigma\Delta t = \Delta t_1 + \Delta t_2 + \Delta t_3 + \Delta t_4 + \Delta t_5$$

Unpowered flight means no fuel is used:

$$\Delta W_{f5} = 0$$

Weight at the end of phase 5:

$$W_5 = W_4$$

Wing Loading:

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

Phase 6: Loiter

Given:

Height, time

$$h, \Delta t$$

$$\sigma$$

Find:

Cumulative (total) time:

$$\Sigma\Delta t = \Delta t_1 + \Delta t_2 + \Delta t_3 + \Delta t_4 + \Delta t_5 + \Delta t_6$$

Maximum endurance (minimum drag) conditions

$$V = V_{md} = \left[\sqrt{\frac{2(W/S)}{\rho_{SL}\sigma}}\right]\left[\sqrt[4]{\frac{K}{C_{DO}}}\right]$$

Thrust for highest efficiency:

$$E = E_m$$

$$\frac{T}{W} = \frac{1}{E_m}$$

$$T = \frac{W}{E_m}$$

Fuel used:

$$\Delta W_{f6} = cT\Delta t$$

Weight at the end of phase 6:

$$W_6 = W_5 - \Delta W_{f6}$$

Wing Loading:

$$\frac{W_6}{S}$$

Part d:

Phase 4: Cruise

<u>Given:</u>

Initial height, Range

$$h_1, X$$

<u>Find:</u>

Speed of sound at h:

$$a = \sigma a_{SL}$$

Velocity at Drag-rise Mach number:

$$V = M_{DR} a$$

Phase time:

$$\Delta t_4 = \frac{X}{V}$$

Cumulative time:

$$\Sigma\Delta t = \Delta t_1 + \Delta t_2 + \Delta t_3 + \Delta t_4$$

Lift coefficient, and drag coefficient during cruise:

$$C_L = \frac{2(W/S)}{\rho_{SL}\sigma_1 V^2}$$

$$C_D = C_{D0} + K{C_L}^2$$

$$E = \frac{C_L}{C_D}$$

Efficiency remains constant throughout cruise.

Re-arranging the Breguet Equation, Fuel consumption can be determined:

$$X = \frac{EV}{c} ln\left(\frac{1}{1-\zeta}\right)$$

$$\Delta W_{f4} = W_3\left[1 - \frac{1}{e^{\frac{cX}{EV}}}\right]$$

Weight at the end of phase 4:

$$W_4 = W_3 - \Delta W_{f4}$$

Wing Loading:

$$\frac{W_4}{S}$$

Final height at the end of phase 4 interpolated from Table B using sigma at the end of phase 4:

$$\sigma_2 = \sigma_1(1 - \zeta)$$

$$h_2$$

Phase 5 and 6 are done in the same way as in the original mission using the final height at phase 4

MATLAB Code

```
%% Aircraft Flight Mechanics Project 2
% Chapter 4 Problem 36
% Marc Rozman
% 11/10/17

clear; clc;

% First run this section for results of phases 1-3 and then run either the
% following section for phases 4-6 results operating under the original
% constant altitude-constant velocity cruise program or the section after
% that for phases 4-6 using the cruise-climb program in part d


% Aircraft B characteristics
W = 140000; % Total Weight [lb]
S = 2333; % Wing Area [ft^2]
Tmax = 37800; % Maximum Thrust at SL [lb]
CD0 = 0.018; % 0 Lift Drag Coefficient
K = 0.048; % Drag Coefficient K constant
MDR = 0.8; % Drag-Rise Mach Number
CLmax = 2.0; % Maximum Lift Coefficient
c = 0.85; % Thrust Specific Fuel Consumption [lb/h/lb]
Emax = 1/(2*sqrt(K*CD0)); % Maximum aerodynamic efficiency (Lift/Drag)

r = 23.769e-4; % Standard Atmoshperic Density at SL [lb*s^2/ft^4]
g = 32.2; % Gravitational Acceleration [ft/s^2]



% Phase 1
% Taxi for 15 minutes at 20 percent of the maximum thrust
disp('Phase 1 Results: ');
```

```
h = 0; % Height [ft]
sigma = 1; % Density ratio to SL
T = 0.2*Tmax; % Thrust [lb]
t = 15/60; % Phase time [h]
time = t*60; % Phase time[min]
cumulativetime = time; % Cumulative time [min]
Wf = c*T*t; % Fuel required [lb]
W = W - Wf; % Weight at end of phase[lb]
WingLoading = W/S; % Wing loading [lb/ft^2]
V = 0; % Airspeed [ft/s]

disp(['The fuel used during phase 1 is: ' num2str(Wf) ' lb']);
disp(['The wing loading at the end of phase 1 is: ' num2str(WingLoading) '
lb/ft^2']);
disp(['The time to complete phase 1 is: ' num2str(time) ' min']);
disp(['The cumulative time up to phase 1 is: ' num2str(cumulativetime) '
min']);
disp(['The airspeed velocity at the end of phase 1 is: ' num2str(V) ' mph']);
disp(' ');



% Phase 2
% Take-off at sea level on a standard day
disp('Phase 2 Results: ');

h = 0; % Height [ft]
sigma = 1; % Density ratio to SL
V = sqrt((2.88*(W/S))/(r*sigma*CLmax)); % Lift-off velocity [ft/s]
Velocity = V*3600/5280; % Lift-off velocity [mph]
t = (V/(g*sigma*(Tmax/W)))/3600; % Phase time [h]
time = t*60; % Phase time[min]
cumulativetime = cumulativetime + time; % cumulative time [min]
Wf = c*Tmax*t; % Fuel required [lb]
W = W - Wf; % Weight at end of phase [lb]
WingLoading = W/S; % Wing loading at end of phase [lb/ft^2]

disp(['The fuel used during phase 2 is: ' num2str(Wf) ' lb']);
disp(['The wing loading at the end of phase 2 is: ' num2str(WingLoading) '
lb/ft^2']);
disp(['The time to complete phase 2 is: ' num2str(time) ' min']);
disp(['The cumulative time up to phase 2 is: ' num2str(cumulativetime) '
min']);
disp(['The airspeed velocity at the end of phase 2 is: ' num2str(Velocity) '
mph']);
disp(' ');



% Phase 3
% Fastest climb to 35000ft at 85 percent of the maximum thrust
disp('Phase 3 Results: ');

h1 = 0; % Initial height [ft]
```

```
sigma1 = 1; % Density ratio to SL at h1
h2 = 35000; % Final height [ft]
sigma2 = 0.310; % Density ratio to SL at h2
T = 0.85*Tmax; % Thrust [lb]
Gamma1 = 1 + sqrt(1 + 3/((Emax*sigma1*(T/W))^2));
V1 = sqrt(((T/S)*Gamma1)/(3*r*CD0)); % Fastest climb velocity at start of
climb (h = 0 ft) [ft/s]
Gamma2 = 1 + sqrt(1 + 3/((Emax*sigma2*(T/W))^2));
V2 = sqrt(((T/S)*Gamma2)/(3*r*CD0)); % Fastest climb velocity at end of climb
(h = 35000ft)[ft/s]
Velocity = V2*3600/5280; % Fastest climb velocity at end of climb [mph]
t = (23800/(T/W))*sqrt((27*r*CD0)/(8*(T/S)))*(exp(h2/23800) - exp(h1/23800));
% Phase time [s]
time = t/60; % Phase time [min]
cumulativetime = cumulativetime + time; % cumulative time [min]
Wf = W*(1-exp((-c/3600)*sqrt((27*r*CD0)/(8*(T/S)))*(h2 - h1))); % Fuel
required [lb]
W = W - Wf; % Weight at end of phase [lb]
WingLoading = W/S; % Wing loading at end of phase [lb/ft^2]

disp(['The fuel used during phase 3 is: ' num2str(Wf) ' lb']);
disp(['The wing loading at the end of phase 3 is: ' num2str(WingLoading) '
lb/ft^2']);
disp(['The time to complete phase 3 is: ' num2str(time) ' min']);
disp(['The cumulative time up to phase 3 is: ' num2str(cumulativetime) '
min']);
disp(['The airspeed velocity at the end of phase 3 is: ' num2str(Velocity) '
mph']);
disp(' ');



%% Phase 4 Original
% Cruise 2000 mi at a constant altitude with a constant airspeed
disp('Phase 4 Results: ');

h = 35000;
sigma = 0.374; % Density ratio to SL
V = sqrt(((2*(W/S))/(r*sigma)))*(3*K/CD0)^0.25; % Best range cruise velocity
[ft/s]
Velocity = V* 3600/5280; % Best range cruise velocity [mph]
X = 2000; % Range [mi]
t = 2000/Velocity; %hours
time = t*60; % [min]
cumulativetime = cumulativetime + time; % [min]
CL = (2*W)/(r*sigma*V^2*S); % Lift coefficient at start of cruise
CD = CD0 + K*CL^2; % Drag coefficient at start of cruise
E = CL/CD; % Lift/Drag ratio at start of cruise
Wf =
W*(((2*Emax/E)*tan(c*X/(2*Emax*Velocity)))/(1+(2*Emax/E)*tan(c*X/(2*Emax*Velo
city))*K*CL*E));
W = W - Wf; % Weight at end of phase [lb]
WingLoading = W/S; % Wing loading at end of phase [lb/ft^2]

disp(['The fuel used during phase 4 is: ' num2str(Wf) ' lb']);
```

```
disp(['The wing loading at the end of phase 4 is: ' num2str(WingLoading) '
lb/ft^2']);
disp(['The time to complete phase 4 is: ' num2str(time) ' min']);
disp(['The cumulative time up to phase 4 is: ' num2str(cumulativetime) '
min']);
disp(['The airspeed velocity at the end of phase 4 is: ' num2str(Velocity) '
mph']);
disp(' ');




% Phase 5
% Descend to sea level (no range, fuel, or time credits)
disp('Phase 5 Results: ');
h1 = 35000; % Initial height [ft]
sigma1 = 0.310; % Density ratio to SL at h1
h2 = 0; % Final height [ft]
sigma2 = 1; % Density ratio to SL at h2
V1 = sqrt(((2*(W/S))/(r*sigma1)))*(K/CD0)^0.25; % Best range airspeed
velocity at start of descent[ft/s]
V2 = sqrt(((2*(W/S))/(r*sigma2)))*(K/CD0)^0.25; % Best range airspeed
velocity at end of descent [ft/s]
Velocity = V2*3600/5280; % Best range airspeed velocity at end of climb [mph]
t = (47600*Emax/V2)*(exp(-h2/47600) - exp(-h1/47600)); % phase time [s]
time = t/60; % Phase time [min]
cumulativetime = cumulativetime + time; % [min]
Wf = 0; % Fuel used [b]
WingLoading = W/S; % Wing loading at end of phase [lb/ft^2]

disp(['The fuel used during phase 5 is: ' num2str(Wf) ' lb']);
disp(['The wing loading at the end of phase 5 is: ' num2str(WingLoading) '
lb/ft^2']);
disp(['The time to complete phase 5 is: ' num2str(time) ' min']);
disp(['The cumulative time up to phase 5 is: ' num2str(cumulativetime) '
min']);
disp(['The airspeed velocity at the end of phase 5 is: ' num2str(Velocity) '
mph']);
disp(' ');




% Phase 6
% Loiter at sea level for 1 hour
disp('Phase 6 Results: ');
h = 0; % height [ft]
sigma = 1; % Density ratio to SL
t = 1; % Phase time [h]
time = t*60; % Phase time[min]
cumulativetime = cumulativetime + time; %min
V = sqrt(((2*(W/S))/(r*sigma)))*(K/CD0)^0.25; % Maximum endurance velocity
[ft/s]
Velocity = V*3600/5280; % Maximum endurance velocity [mph]
T = W/Emax; % Thrust [lb]
Wf = c*T*t; % Fuel required [lb]
W = W - Wf; % Weight
```

```
WingLoading = W/S; % Wing loading at end of phase [lb]

disp(['The fuel used during phase 6 is: ' num2str(Wf) ' lb']);
disp(['The wing loading at the end of phase 6 is: ' num2str(WingLoading) '
lb/ft^2']);
disp(['The time to complete phase 6 is: ' num2str(time) ' min']);
disp(['The cumulative time up to phase 6 is: ' num2str(cumulativetime) '
min']);
disp(['The airspeed velocity at the end of phase 6 is: ' num2str(Velocity) '
mph']);
disp(' ');



%% Part d
% Phase 4
% Cruise-climb flight at MDR (constant velocity and constant lift
coefficient) for
% a range of 2000 miles
disp('Phase 4 Results: ')

h1  = 35000; % Initial height [ft]
sigma1 = 0.310; % Density ratio to SL at h1
a = 0.871*1116; % Speed of sound at h1
V = MDR*a; % Cruise velocity [ft/s]
Velocity = V*3600/5280; % Cruise velocity [mph]
X = 2000; % Range [mi]
t = X/Velocity; % Phase time [h]
time = t*60; % Phase time [min]
cumulativetime = cumulativetime + time; % Cumulative time [min]
CL = (2*W)/(r*sigma1*V^2*S); % Lift coefficient
CD = CD0 + K*CL^2; % Drag coefficient
E = CL/CD; % Lift/Drag Ratio
Wf = W*(1-(1/exp(c*X/(E*Velocity)))); % Fuel used [lb]
sigma2 = sigma1*(1-Wf/W); % Density ratio to SL at h2
h2 = 40730; % Final height[ft] (height at sigma2 = 0.2384)
W = W - Wf; % Weight at end of phase [lb]
WingLoading = W/S;

disp(['The fuel used during phase 4 is: ' num2str(Wf) ' lb']);
disp(['The wing loading at the end of phase 4 is: ' num2str(WingLoading) '
lb/ft^2']);
disp(['The time to complete phase 4 is: ' num2str(time) ' min']);
disp(['The cumulative time up to phase 4 is: ' num2str(cumulativetime) '
min']);
disp(['The airspeed velocity at the end of phase 4 is: ' num2str(Velocity) '
mph']);
disp(' ');



% Phase 5
% Descend to sea level (no range, fuel, or time credits)
disp('Phase 5 Results: ');
```

```
h1 = h2; % Initial height [ft]
sigma1 = sigma2; % Density ratio to SL at h1
h2 = 0; % Final height [ft]
sigma2 = 1; % Density ratio to SL at h2 [ft]
V1 = sqrt(((2*(W/S))/(r*sigma1)))*(K/CD0)^0.25; % Best range airspeed
velocity at start of descent[ft/s]
V2 = sqrt(((2*(W/S))/(r*sigma2)))*(K/CD0)^0.25; % Best range airspeed
velocity at end of descent [ft/s]
Velocity = V2*3600/5280; % Velocity [mph]
t = (47600*Emax/V2)*(exp(-h2/47600) - exp(-h1/47600)); % Phase time [s]
time = t/60; % Phase time [min]
cumulativetime = cumulativetime + time; % Cumulative time [min]
Wf = 0; % Fuel used [lb]
WingLoading = W/S; % Wing loading at end of phase [lb/ft^2]

disp(['The fuel used during phase 5 is: ' num2str(Wf) ' lb']);
disp(['The wing loading at the end of phase 5 is: ' num2str(WingLoading) '
lb/ft^2']);
disp(['The time to complete phase 5 is: ' num2str(time) ' min']);
disp(['The cumulative time up to phase 5 is: ' num2str(cumulativetime) '
min']);
disp(['The airspeed velocity at the end of phase 5 is: ' num2str(Velocity) '
mph']);
disp(' ');



% Phase 6
% Loiter at sea level for 1 hour
disp('Phase 6 Results: ');

h = 0; % height [ft]
sigma = 1; % Density ratio to SL at h
t = 1; % Phase time [h]
time = t*60; % Phase time [min]
cumulativetime = cumulativetime + time; % Cumulative time [min]
V = sqrt(((2*(W/S))/(r*sigma)))*(K/CD0)^0.25; % Maximum endurance (lowest
drag) velocity [ft/s]
Velocity = V*3600/5280; % Maximum endurance (lowest drag) velocity [mph]
T = W/Emax; % Thrust
Wf = c*T*t; % Fuel required [lb]
W = W - Wf; % Weight at end of phase [lb]
WingLoading = W/S; % Wing loading at end of phase [lb]

disp(['The fuel used during phase 6 is: ' num2str(Wf) ' lb']);
disp(['The wing loading at the end of phase 6 is: ' num2str(WingLoading) '
lb/ft^2']);
disp(['The time to complete phase 6 is: ' num2str(time) ' min']);
disp(['The cumulative time up to phase 6 is: ' num2str(cumulativetime) '
min']);
disp(['The airspeed velocity at the end of phase 6 is: ' num2str(Velocity) '
mph']);
disp(' ');
```

MATLAB Results

Original: Constant height-constant velocity cruise program

Phase 1 Results:

The fuel used during phase 1 is: 1606.5 lb

The wing loading at the end of phase 1 is: 59.32 lb/ft^2

The time to complete phase 1 is: 15 min

The cumulative time up to phase 1 is: 15 min

The airspeed velocity at the end of phase 1 is: 0 mph

Phase 2 Results:

The fuel used during phase 2 is: 192.3767 lb

The wing loading at the end of phase 2 is: 59.2375 lb/ft^2

The time to complete phase 2 is: 0.35925 min

The cumulative time up to phase 2 is: 15.3592 min

The airspeed velocity at the end of phase 2 is: 129.2543 mph

Phase 3 Results:

The fuel used during phase 3 is: 3649.0434 lb

The wing loading at the end of phase 3 is: 57.6734 lb/ft^2

The time to complete phase 3 is: 18.5176 min

The cumulative time up to phase 3 is: 33.8768 min

The airspeed velocity at the end of phase 3 is: 369.078 mph

Phase 4 Results:

The fuel used during phase 4 is: 35298.6777 lb

The wing loading at the end of phase 4 is: 42.5432 lb/ft^2

The time to complete phase 4 is: 290.5217 min

The cumulative time up to phase 4 is: 324.3985 min

The airspeed velocity at the end of phase 4 is: 413.05 mph

Phase 5 Results:

The fuel used during phase 5 is: 0 lb

The wing loading at the end of phase 5 is: 42.5432 lb/ft^2

The time to complete phase 5 is: 29.0593 min

The cumulative time up to phase 5 is: 353.4579 min

The airspeed velocity at the end of phase 5 is: 164.8487 mph

Phase 6 Results:

The fuel used during phase 6 is: 4959.6519 lb

The wing loading at the end of phase 6 is: 40.4174 lb/ft^2

The time to complete phase 6 is: 60 min

The cumulative time up to phase 6 is: 413.4579 min

The airspeed velocity at the end of phase 6 is: 164.8487 mph

Part d: Cruise-climb program

Phase 1 Results:

The fuel used during phase 1 is: 1606.5 lb

The wing loading at the end of phase 1 is: 59.32 lb/ft^2

The time to complete phase 1 is: 15 min

The cumulative time up to phase 1 is: 15 min

The airspeed velocity at the end of phase 1 is: 0 mph

Phase 2 Results:

The fuel used during phase 2 is: 192.3767 lb

The wing loading at the end of phase 2 is: 59.2375 lb/ft^2

The time to complete phase 2 is: 0.35925 min

The cumulative time up to phase 2 is: 15.3592 min

The airspeed velocity at the end of phase 2 is: 129.2543 mph

Phase 3 Results:

The fuel used during phase 3 is: 3649.0434 lb

The wing loading at the end of phase 3 is: 57.6734 lb/ft^2

The time to complete phase 3 is: 18.5176 min

The cumulative time up to phase 3 is: 33.8768 min

The airspeed velocity at the end of phase 3 is: 369.078 mph

Phase 4 Results:

The fuel used during phase 4 is: 31093.8929 lb

The wing loading at the end of phase 4 is: 44.3456 lb/ft^2

The time to complete phase 4 is: 226.3291 min

The cumulative time up to phase 4 is: 260.2059 min

The airspeed velocity at the end of phase 4 is: 530.2015 mph

Phase 5 Results:

The fuel used during phase 5 is: 0 lb

The wing loading at the end of phase 5 is: 44.3456 lb/ft^2

The time to complete phase 5 is: 31.4349 min

The cumulative time up to phase 5 is: 291.6408 min

The airspeed velocity at the end of phase 5 is: 168.3044 mph

Phase 6 Results:

The fuel used during phase 6 is: 5169.7633 lb

The wing loading at the end of phase 6 is: 42.1296 lb/ft^2

The time to complete phase 6 is: 60 min

The cumulative time up to phase 6 is: 351.6408 min

The airspeed velocity at the end of phase 6 is: 168.3044 mph

Final Results

Original Mission Profile with Constant Altitude-Constant Velocity Cruise

Phase	$\Delta W_f\ [lb]$	$W/S\ \left[\frac{lb}{ft^2}\right]$	$V\ [mph]$	$\Delta t\ [min]$	$\Sigma\Delta t\ [min]$
1	1607	59.3	0	15.00	15.00
2	192	59.2	129	0.36	15.36
3	3649	57.7	369	18.52	33.88
4	35299	42.5	413	290.52	324.40
5	0	42.5	165	29.06	353.46
6	4960	40.4	165	60	413.46

$$\boldsymbol{Minimum\ total\ fuel\ required, W_f = 45707\ lb}$$

$$\boldsymbol{Total\ time, \Delta t = 413\ min}$$

Part d Mission Profile with Cruise-Climb

Phase	$\Delta W_f\ [lb]$	$W/S\ \left[\frac{lb}{ft^2}\right]$	$V\ [mph]$	$\Delta t\ [min]$	$\Sigma\Delta t\ [min]$
1	1607	59.3	0	15.00	15.00
2	192	59.2	129	0.36	15.36
3	3649	57.7	369	18.52	33.88
4	31094	44.3	530	226.33	260.21
5	0	44.3	168	31.43	291.64
6	5170	42.1	168	60.00	351.64

$$\boldsymbol{Minimum\ total\ fuel\ required, W_f = 41712\ lb}$$

$$\boldsymbol{Total\ time, \Delta t = 351min}$$

The mission profile using the cruise-climb program is faster and has better overall fuel economy than the mission profile that cruises at constant altitude-constant velocity.