%% Aerodynamic / wing properties

% General

a.AR = 10; % Wing aspect ratio [-]

a.Lambda = -2.8; % Half-chord sweep angle of wing [deg]

a.TR = 0.4; % Taper ratio of wing [-]

a.tc = 0.12; % Thickness-to-chord ratio of root section [-]

a.nUlt = 4.4; % Ultimate load factor [-]

% maximum lift coefficient (no propulsive interaction assumed)

CLmax\_clean=1.5;

CLmax\_TO=1.7;

CLmax\_L=1.5 + 0.52; % 2.37 2.1

% Oswald factor (no propulsive interaction assumed)

e\_clean=0.82;

e\_TO=0.77;

e\_L=0.73;

% zero-lift drag coefficient (no propulsive interaction assumed)

CD0\_clean=0.0338; % 0.0355

CD0\_TO= CD0\_clean + 0.015;

CD0\_L=CD0\_clean + 0.055;

% Cruise

a.cr.CD0 = CD0\_clean; % Cruise zero-lift drag coefficient [-]

a.cr.e = e\_clean; % Cruise oswald factor [-]

% Landing

a.L.CD0 = CD0\_L; % Landing zero-lift drag coefficient [-]

a.L.e = e\_L; % Landing oswald factor [-]

a.L.CLmax = CLmax\_L; % Landing maximum lift coefficient of isolated wing [-]

% Take off

a.TO.CD0 = CD0\_TO; % TO zero-lift drag coefficient [-]

a.TO.e = e\_TO; % TO oswald factor [-]

a.TO.CLmax = CLmax\_TO; % TO maximum lift coefficient of isolated wing [-]

% OEI Balked landing

a.bL.CD0 = CD0\_L; % OEI balked landing zero-lift drag coefficient (LG retracted) [-]

% CLmax, e, assumed to be the same as in landing configuration.

% OEI Ceiling

a.cI.CD0 = CD0\_clean; % Ceiling (OEI) zero-lift drag coefficient [-]

a.cI.e = e\_clean ; % Ceiling (OEI) oswald factor [-]

a.cI.CLmax = CLmax\_clean; % Clean configuration max lift coefficient of isolated wing [-]

% Start-of-climb

a.cl.CD0 = CD0\_clean; % Start-of-climb zero-lift drag coefficient [-]

a.cl.e = e\_clean; % Start-of-climb oswald factor [-]

a.cl.CLmax = CLmax\_clean; % Start-of-climb maximum lift coefficient of isolated wing [-]

% Top-of-climb

a.ct.CD0 = CD0\_clean; % Top-of-climb zero-lift drag coefficient [-]

a.ct.e = e\_clean; % Top-of-climb oswald factor [-]

a.ct.CLmax = CLmax\_clean; % Top-of-climb maximum lift coefficient of isolated wing [-]

%% Propulsion System

% Propulsion system layout

p.config = 'SPPH'; % Powertrain architecture ('conventional', 'turboelectric', 'serial',

% 'parallel', 'PTE', 'SPPH', 'e-1', 'e-2', or 'dual-e')

p.b\_dp = 0.5; % Fraction of wing span occupied by DP system [-]

p.dy = 0.01; % Spacing between adjacent DP propulsors, as fraction of propulsor diameter [-]

p.N1 = 2; % Number of chains in primary powertrain [-]

p.N2 = 4; % Number of chains in secondary powertrain[-]

p.DP = 2; % Which PS has an effect on wing performance? (1 = primary, 2 = secondary, 0 = none)

p.xp = -0.25; % Axial position of propellers as a fraction of chord

% xp < 0: tractor

% 0 < xp < 1: OTW

% xp > 1: pusher

% xp = Inf: No effect of prop on wing

% Component properties (excl. propulsive)

p.eta\_EM1 = 0.95; % Conversion efficiency of (electro-) generators

p.eta\_EM2 = 0.95; % Conversion efficiency of electromotors

p.eta\_PM = 0.95; % Conversion efficiency of PMAD

p.eta\_GB = 0.95; % Transmission efficiency of gearboxes

p.eta\_GT = 0.35; % Conversion (thermal) efficiency of gas turbine

p.SE.bat = 1.6e6; % Battery specific energy [J/kg] http://assets.solidenergysystems.com/wp-content/uploads/2017/09/08171937/Hermes\_Spec\_Sheet1.pdf

p.SE.f = 42.8e6; % Fuel specific energy [J/kg]

p.SP.EM = 8.57e3; % 7.7 http://emrax.com/products/emrax-188/ % Electrical machine specific power [W/kg]

p.SP.bat = 2000; % Battery pack specific power [W/kg]

p.minSOC\_miss = 0.2; % Minimum SOC (maximum discharge) of batteries after nominal mission [-]

p.minSOC\_tot = 0; % Minimum SOC (maximum discharge) of batteries after diversion mission [-]

% Cruise

p.cr.etap1 = 0.8; % Primary propulsors' propulsive efficiency in cruise (of ISOLATED propulsors) [-]

p.cr.etap2 = 0.8; % Secondary propulsors' propulsive efficiency in cruise (of ISOLATED propulsors) [-]

p.cr.Gamma = 0; % Thrust vectoring in cruise [deg]

% Landing

p.L.etap1 = 0.8; % Primary propulsors' propulsive efficiency in landing conditions (of ISOLATED propulsors) [-]

p.L.etap2 = 0.75; % Secondary propulsors' propulsive efficiency in landing conditions (of ISOLATED propulsors) [-]

p.L.Gamma = 0; % Thrust vectoring in landing configuration [deg]

% Take off

p.TO.etap1 = 0.65; % Primary propulsors' propulsive efficiency in TO conditions (of ISOLATED propulsors) [-]

p.TO.etap2 = 0.65; % Secondary propulsors' propulsive efficiency in TO conditions (of ISOLATED propulsors) [-]

p.TO.Gamma = 0; % Thrust vectoring in TO configuration [deg]

% OEI Balked landing

p.bL.etap1 = 0.8; % Primary propulsors' propulsive efficiency in balked landing conditions (of ISOLATED propulsors) [-]

p.bL.etap2 = 0.8; % Secondary propulsors' propulsive efficiency in balked landing conditions (of ISOLATED propulsors) [-]

p.bL.Gamma = 0; % Thrust vectoring in balked landing configuration [deg]

% OEI ceiling

p.cI.etap1 = 0.8; % Primary propulsors' propulsive efficiency in ceiling (OEI) conditions (of ISOLATED propulsors) [-]

p.cI.etap2 = 0.8; % Secondary propulsors' propulsive efficiency in ceiling (OEI) conditions (of ISOLATED propulsors) [-]

p.cI.Gamma = 0; % Thrust vectoring in ceiling (OEI) configuration [deg]

% Start-of-climb

p.cl.etap1 = 0.75; % Primary propulsors' propulsive efficiency in climb conditions (of ISOLATED propulsors) [-]

p.cl.etap2 = 0.75; % Secondary propulsors' propulsive efficiency in start-of-climb conditions (of ISOLATED propulsors) [-]

p.cl.Gamma = 0; % Thrust vectoring in start-of-climb configuration [deg]

% Top-of-climb

p.ct.etap1 = 0.8; % Primary propulsors' propulsive efficiency in top-of-climb conditions (of ISOLATED propulsors) [-]

p.ct.etap2 = 0.8; % Secondary propulsors' propulsive efficiency in top-of-climb conditions (of ISOLATED propulsors) [-]

p.ct.Gamma = 0; % Thrust vectoring in top-of-climb configuration [deg]

%% Mission/operational requirements for WP diagram

% Note: the throttle, phi and Phi values used to evaluate the constraints

% should be consistent with the power-control profiles specified in the MA.

% In future revisions, t, phi and Phi should automatically be selected from

% the MA\_in structure (by e.g. evaluating the maximum and minimum per

% segment).

% Cruise

m.cr.h = 2400; % Cruise altitude [m]

m.cr.M = 0.2797; % Cruise Mach number [-]

m.cr.f = 0.999; % Cruise weight fraction W/MTOW [-]

m.cr.t = 0.8; % Cruise throttle setting P/P\_max [-] (see note at end)

m.cr.phi = 0; % Cruise supplied power ratio [-]

m.cr.Phi = 0; % Cruise shaft power ratio [-]

% Landing

m.L.h = 0; % Landing altitude [m]

m.L.f = 0.97; % Landing weight fraction W/MTOW [-]

m.L.vs = 31.4; % Stall speed requirement in landing conditions [m/s]

m.L.vApp = 1.23; % Stall margin during approach/landing, vApp/vs [-] (see Patterson 2017)

m.L.vAppIso = 1.05; % Stall margin of isolated wing during approach/landing, vApp/vsIso [-]

m.L.t = 0.4; % Landing throttle setting P/P\_max [-] (see note at end)

m.L.phi = 0.6; % Landing supplied power ratio [-]

m.L.Phi = 0.6; % Landing shaft power ratio [-]

% Take off

m.TO.h = 0; % TO altitude [m]

m.TO.f = 0.8; % TO weight fraction W/MTOW [-]

m.TO.s = 762; % TO runway length [m]

m.TO.t = 1; % TO throttle setting P/P\_max [-] (see note at end)

m.TO.phi = 0.14; % TO supplied power ratio [-]vv0.14

m.TO.Phi = 0.09; % TO shaft power ratio [-] . 0.09

% OEI Balked landing

m.bL.G = 0.021; % OEI balked landing climb gradient [-] (CS25.121d)

m.bL.f = 0.97; % Max landing weight (MLW) as a fraction of MTOW [-]

m.bL.vMargin = 1.4; % Stall margin in balked-landing conditions

m.bL.t = 1; % Balked landing throttle setting P/P\_max [-] (see note at end)

m.bL.phi = 0.08; % Balked landing supplied power ratio [-]

m.bL.Phi = 0.04; % Balked landing shaft power ratio [-]

% OEI ceiling

m.cI.h = 1200; % OEI ceiling [m]

m.cI.f = 0.999; % OEI-ceiling weight fraction W/MTOW [-]

m.cI.c = 0.5; % Ceiling climb rate [m/s] (also used for cruise ceiling and cruise speed!)

m.cI.vMargin = 1.25; % Stall margin in OEI-ceiling conditions (also used for cruise ceiling) CHECK!

m.cI.t = 1; % OEI-ceiling throttle setting P/P\_max [-] (see note at end)

m.cI.phi = 0.02; % OEI-ceiling landing supplied power ratio [-]

m.cI.Phi = 0.1; % OEI-ceiling landing shaft power ratio [-]

% Start-of-climb

m.cl.h = 0; % Altitude for start-of-climb constraint [m]

m.cl.f = 1; % Start-of-climb weight fraction W/MTOW [-]

m.cl.v = 37.4; % Velocity at start-of-climb (shoud be equal to V2 obtained from TO constraint) [m/s]

m.cl.G = 0.02; % Start-of-climb climb gradient [-] (based on MA observances)

m.cl.dVdt = 0.5; % Start-of-climb acceleration [m/s2]

m.cl.t = 1; % Start-of-climb throttle setting P/P\_max [-] (see note at end)

m.cl.phi = 0.07; % Start-of-climb supplied power ratio [-]

m.cl.Phi = 0.3; % Start-of-climb shaft power ratio [-]

% Top-of-climb

m.ct.h = 2400; % Altitude for top-of-climb constraint [m]

m.ct.f = 0.999; % Start-of-climb weight fraction W/MTOW [-]

m.ct.M = 0.2797; % Mach at top-of-climb (shoud be equal to cruise Mach) [-]

m.ct.G = 0.01; % Top-of-climb climb gradient [-] (based on MA observances)

m.ct.dVdt = 0.06; % Top-of-climb acceleration [m/s2]

m.ct.t = 1; % Top-of-climb throttle setting P/P\_max [-] (see note at end)

m.ct.phi = 0.05; % Top-of-climb supplied power ratio [-]

m.ct.Phi = 0.3; % Top-of-climb shaft power ratio [-]

%% Mission Analysis input

% Mission characteristics

MA\_in.PL = 363; % Payload [kg]

MA\_in.R = 463000; % Range [m]

MA\_in.R\_div = 187515; % Diversion range [m]

MA\_in.h\_div = 914; % Diversion altitude [m]

MA\_in.M\_div = 0.207; % Diversion cruise Mach number [-]

% Nominal mission M and h are specified in the

% "m" structure (cruise constraint)

% Initial guesses for convergence loop

MA\_in.OEM = 1347; % Operative empty mass incl. powertrain and wing, excl. bat [kg]

MA\_in.FF\_tot0 = 0.1; % Fuel fraction (excl. batteries, incl. diversion) of aircraft [-]

MA\_in.FF\_miss0 = 0.1; % Fuel fraction (excl. batteries, excl. diversion) of nominal mission [-]

MA\_in.DOH\_tot0 = 0.1; % Degree-of-hybridization, Ebat/(Efuel + Ebat) of aircraft [-]

MA\_in.DOH\_miss0 = 0.1; % Degree-of-hybridization, Ebat/(Efuel + Ebat) of nominal mission [-]

% Mission analysis power control settings. Linear interpolation used

% between [start of segment, end of segment]. For climb and descent,

% interpolation is carried out versus altitude, and for cruise, versus

% range flown.

% Climb (all parameters must be specified; SEP is computed)

MA\_in.cl.xi = [0.7 0.8];

MA\_in.cl.phi = [0.05 0.05];

MA\_in.cl.Phi = [0.05 0.05];

% Cruise (level flight is specified, so one DOF must be kept free)

MA\_in.cr.xi = [NaN NaN];

MA\_in.cr.phi = [0 0];

MA\_in.cr.Phi = [0 0];

% Descent (all parameters must be specified; SEP is computed)

MA\_in.de.xi = [0.02 0.02];

MA\_in.de.phi = [0.6 0.6];

MA\_in.de.Phi = [0.6 0.6];

% Diversion climb (all parameters must be specified; SEP is computed)

MA\_in.Dcl.xi = [0.5 0.5];

MA\_in.Dcl.phi = [0.05 0.05];

MA\_in.Dcl.Phi = [0.05 0.05];

% Diversion cruise (level flight is specified, so one DOF must be kept free)

MA\_in.Dcr.xi = [NaN NaN];

MA\_in.Dcr.phi = [0 0];

MA\_in.Dcr.Phi = [0 0];

% Diversion descent (all parameters must be specified; SEP is computed)

MA\_in.Dde.xi = [0.01 0.01];

MA\_in.Dde.phi = [0.01 0.1];

MA\_in.Dde.Phi = [0.05 0.05];

%% Constants

c.g = 9.81; % Gravity acceleration [m/s2]

c.rho\_SL = 1.225; % Sea-level density [kg/m3]

c.T\_SL = 288.15; % Sea-level temperature [K]

%% Program settings

% Design considerations

s.SelDes = 'minWS'; % Selected design condition ('minWS','minGT',...)

s.Tcmax = 2; % Maximum thrust coefficient (defined as Tc = T/rho/v^2/D^2) that

% each individual propulsor should not surpass

% Convergence settings

s.n = 100; % Number of points sampled per constraint [-]

s.TWmax = 1.0; % Maximum thrust loading evaluated [-]

s.WSmax = 10000; % Maxumum wing loading evaluated [N/W]

s.WSmin = 0; % Minimum wing loading evaluated for landing constraint [N/W]

s.WPmax = 0.3; % Maximum power loading shown in diagram [N/W]

s.itermax = 500; % Maximum number of iterations [-]

s.errmax = 1e-4; % Convergence criterion

s.NWS = 300; % Number of wing loading points to sample when computing design point

s.rf = 0.6; % Relaxation factor for convergence, recommended values [0.1 - 1.0].

% Lower RF = slower, but generally more chance of convergence

s.dt.cl = 15; % Time step in MA, climb phase [s]

s.dt.cr = 40; % Time step in MA, cruise phase [s]

s.dt.de = 20; % Time step in MA, descent phase [s]

s.dt.Dcl = 5; % Time step in MA, diversion climb phase [s]

s.dt.Dcr = 30; % Time step in MA, diversion climb phase [s]

s.dt.Dde = 15; % Time step in MA, diversion climb phase [s]

% Presentation of results

s.levelString = []; % String inserted at the start of each displayed message

s.options = 0; % Plot figures etc. in subroutines (careful with loops!)

s.figStart = 10; % Number of first figure generated

s.plotWPWS = 1; % Plot WS-WP diagrams?

s.plotMA = 1; % Plot mission analysis graphs?

s.plotPowertrain = 1; % Plot powertrain diagrams?

s.plotTc = 1; % Plot thrust coefficient constraints?

% Polar characteristics

s.Polar.plot = 1; % Plot aerodynamic polar?

s.Polar.TcInterval = [0 2]; % Thrust coeff. interval sampled when creating aero polar

s.Polar.MInterval = [0 0.9]; % Mach number interval sampled when creating aero polar

s.Polar.CLisoInterval = [0.3 1.8]; % Airframe lift coeff. interval sampled when creating aero polar. Avoid extremely low/high values

s.Polar.N = 20; % Number of N and Tc points sampled in polar

s.Polar.N\_CLiso = 100; % Number of CL\_iso points sampled in polar

% Landing constraint check characteristics

s.LandingCheck.plot = 1; % Plot detailed landing constraint?

s.LandingCheck.CL\_map = 0.1:0.2:3.0; % Isolated wing CL values plotted during landing constraint check [-]

s.LandingCheck.CD0\_map = [0.04:0.02:0.1 ... % CD0 values plotted during landing constraint check [-]

0.15:0.05:0.4 0.5:0.1:1];

% Power-control envelope characteristics

s.Env.plot = 0; % Plot power-control envelope?

s.Env.Nphi = 50; % Number of phi/Phi values sampled

s.Env.Nxi = 40; % Number of xi values sampled

s.Env.Nh = 30; % Number of altitudes sampled

s.Env.con = 'cr'; % Condition used for propulsive efficiency

s.Env.SPPH\_phis = [0.05 0.2 NaN NaN]; % Constant phi values, for each of one an envelope is created

s.Env.SPPH\_Phis = [NaN NaN 0.4 0.6]; % Constant Phi values, for each of one an envelope is created

% The length of SPPH\_phis same. For each element i, only ONE of the two can

% be specified. The other must be NaN.

%% Functions & Dependencies

% Density lapse [kg/m3]

f.rho = @(h) c.rho\_SL\*(c.T\_SL./(c.T\_SL-0.0065\*h)).^(1-9.81/287/0.0065);

% Speed of sound [m/s]

f.a = @(h) ((c.T\_SL-0.0065\*h)\*1.4\*287)^0.5;

% Take-off parameter correlation [N2/m2/W], s in [m]

% First option: from AE1222-II course

% A = 0.0812;

% B = 8.52;

% Second option: from Raymer

f.TOP = @(s) 0.084958084\*s+6.217443298;

% Normalized rotor sizing: D^2/W [m2/N]

f.D2W = @(WS,b\_dp,N,dy,AR) (b\_dp/N/(1+dy))^2\*AR/WS;

% Thrust lapse: T\_max/T\_max\_SL [-]

f.Alpha = @(rho) (rho/c.rho\_SL)^0.75;

% Drag model: currently assuming a symmetric parabolic drag polar [-]

f.CD = @(CD0,CL\_iso,AR,e) CD0 + CL\_iso^2/(pi\*AR\*e);

% Weight correlations (per component instance!)

% Turboshaft weight in [kg] as a function of shaft

% power in [W], based on Roskam Part 5, Figure 6.2.

f.W.GT = @(P) 0.45359\*10.^((log10(P/745.7)-0.011405)/1.1073);

% OEM in [kg] as a function of MTOM [kg], based on Roskam Part 1,

% Table 2.15 (in lb: 10.^((log10(MTOM)-AA)/BB))

% AA = 0.3774; BB = 0.9647; % Regional turboprop aircraft

% AA = 0.0833; BB = 1.0383; % Transport jets

% AA = 0.0966; BB = 1.0298; % twin turbo prop

f.W.OEM = @(MTOM) 0.45359\*10.^((log10(MTOM/0.45359)-0.0966)/1.0298);

% Electrical machine weight in [kg] as a function of installed power in

% [W]. Using a constant power density for now.

f.W.EM = @(P) P/p.SP.EM;

% Ratio between SEP used to climb and total SEP (i.e. used to climb and

% accelerate). X will be in the interval [0,1].

f.SEPsplit = @(X) 0.83+0.1\*cos(X\*pi);

%% Notes

% Note regarding current nomenclature: the symbols used to designate

% some of the variables has changed over the course of developing this

% code. This should be fixed throughout the code, but for now:

% - Throttle is indicated with "t", or "xi" (in some subroutines).

% - "phi" is the supplied power ratio.

% - "Phi" is the shaft power ratio, although this variable is represented

% with "Psi" in literature (see the paper of de Vries, Brown & Vos,

% 2018)

% - The thrust share provided by the propulsors (which is related to Phi)

% is indicated using "T", which is not (only) the thrust of the

% aircraft, but the thrust produced by the DP propulsors divided by

% the total thrust of the aircraft. In the paper this is represented

% with a "Chi".

%

% Note regarding the "throttle":

% - For powertrain architectures containing a gas turbine (conventional,

% turboelectric, serial, parallel, PTE or SPPH), this refers to the

% throttle setting of the gas turbine, P\_gt/P\_gt\_available, where

% P\_gt\_available is the maximum power available in the given flight