RateOfClimb.m user guide

Rosa Castiello, Raffaella Scarano

Contents

1 Introduction

Rate of climb

The rate of climb is calculated as:

$$P_{avai} - (P_{request})_{FF} = T_{TPP} \cdot V_r \sin\gamma_r = T_{TPP} \cdot V_c \qquad (1.1)$$

Where TPP is for tip path plane and FF is for forward flight.

Figura 1.1: Triangle of speeds of a generic helicopter [1].

2 Inputs and outputs

2.1 Inputs

The function has the following inputs:

> helicopter weigth (W_{t0}), Total Required Power (Ptot_req), Available Power (Pavai), Asymptotic Current Speed (V_{inf}).

2.2 Outputs

The function has the following outputs:

> Rate Of Climb (RC), Fastest Climb Speed (Vy), Maximum Rate Of Climb (RC_rapid), Steepest Climb Speed (Vx), Angle of Maximum Rate Of Climb (gamma_ripid).

3 Function description

This function calculates:

- rate of climb;
- the fastest climb speed (Vy), at which we have the maximum rate of climb (RC_rapid);
- the steepest climb (Vx), at which we have the maximum climbing angle (gamma_ripid)

at different altitudes and weights.

```
function [RC,...
          Vy, RC_rapid,...
          Vx, gamma_ripid] = RateOfClimb(Wto, Ptot_req,Pavai,Vinf)


     RC = (Pavai - Ptot_req)./Wto;    %(Pavai-Ptot_req) is Power in excess

    for i=1:length(RC)
        if RC(i)<0
            RC(i) = 0;    % If RC<0 we don't have the Required Power to climb
        end
    end


    for i=1:length(Vinf)
       if (RC(i) == max(RC))
           Vy = Vinf(i);     % Vy is the fastest climb speed,
                             %at which we have the maximum rate of climb
           RC_rapid = RC(i);
       end
       if (RC(i)/Vinf(i) == max(RC./Vinf))
           Vx = Vinf(i);                % Vx is the steepest climb, at which
                                        %we have the maximum climbing angle
           RC_ripid = RC(i);
           gamma_ripid = asin(RC_ripid/Vx)*180/pi;

       end
    end

end
```

4 Test Case

A test case was performed.

```
clc; close all; clear all;

 % DATA


  % 1) aircraft
    Wto          = 9979.03*9.81;      % [N]
    Pd_sl          = 2110000;         % [W]
    h            = 0;                 % [m]

    T0 = 288; % K
    mu0 = 1.79e-5; % Kg/(ms)
    [Temp, a0, P0, rho] = atmosisa(h);
```

```
    mu_viscoso = mu0*(Temp/T0)^1.5*(T0+110)/(Temp+110);  % Sutherlan's law

   % 2) main rotor                        % tail rotor
    N         = 4;                         N_rc      = 4;
    R_rp      = 8.18;                      R_rc      = 1.7;          % [m]
    A_rp      = pi*R_rp^2;                 A_rc      = pi*R_rc^2;    % [m^2]
    c         = 0.53;                      c_rc      = 0.2;          % [m]
    sigma_rp = 0.082;                      sigma_rc = 0.188;
    Vtip      = 220.98;                    Vtip_rc  = 208.79;        % [m/s]
    Omega_rp = Vtip/R_rp;                  Omega_rc = Vtip_rc/R_rc;
    n         = Omega_rp/(2*pi);           n_rc      = Omega_rc/(2*pi);

                           br = 10.73;       % [m]

    theta1_rp = -18;                         theta1_rc = -17;         % [deg]
    Num        = 10;
    r_rp       = linspace(0.05,R_rp,Num);  r_rc       = linspace(0.05,R_rc,Num);
    r_adim_rp = r_rp/R_rp;                   r_adim_rc = r_rc./R_rc;

  Cd_rc=0.01;
  Cd_rp=0.01;

 k = 1.15;
num  = 120;


Vinf    = linspace(0,120,num);


P_aus    = 25000;  % [W]
P_ausil = P_aus*ones(1,length(Vinf));
eta_rc   = 1.03;

%available power
v_h = linspace(0, 1800, length(Vinf));
[~, ~, ~, rho_sl] = atmosisa(0);
for j = 1:length(v_h)
  [a,b,c,density] = atmosisa(v_h(j));
  v_Pavailable(j)= Pd_sl*density/rho_sl;
end
figure
plot(v_h,v_Pavailable, 'k');
xlabel('h [m]'); ylabel('P_a_v_a_i [W]'); title('Avaiable Power at different h');
grid on;

v_WTO = [0.75*Wto,0.90*Wto, Wto];


h = [0,1000,1800];


v_input=[R_rp,A_rp,sigma_rp, Omega_rp, Cd_rp,...
       R_rc, A_rc, sigma_rc, Omega_rc, Cd_rc,...
         br, k, P_aus, eta_rc, Pd_sl ];

for i = 1:length(h)
for j = 1:length(v_WTO)

    [Pind_B,  Pparas_rp,Pfus,Ptot_rp,...
     Pind_rc,  Pparassita_rc, Ptot_rc,Ptot_request(j,:),Pdisp,...
     V_NE,V_BE, V_BR] = PowerInForwardFlight_main_tail_rotor(h(i), Vinf,
v_WTO(j),v_input);

    Pavaiable(j,:) = Pdisp*ones(1,length(Vinf));

    if (h(i) == 0   &&   v_WTO(j) == Wto)

    figure
    plot(Vinf,Pind_B,'k-.',Vinf,Pparas_rp,'k--',Vinf,Pfus,'k:',Vinf,Ptot_rp,'k-
',Vinf,Pavaiable(j,:),'.-k');
    hold on;
```

```
    xlabel('V_∞ [m/s]'); ylabel('P [W]'); title('Required Power of the main rotor in
forward flight');
    subtitle(['altitude h = ',num2str(h(i)), 'm']);
    legend('P_i_n_d','P_p_a_r','P_f_u_s_o_l_a_g_e','P_t_o_t','P_a_v_a_i');
    grid on



    figure
    plot(Vinf,Pparassita_rc,'k-.',Vinf,Pind_rc,'k--',Vinf,Ptot_rc,'k-');
    title('Powers of the tail rotor'); xlabel('V_∞ [m/s]'); ylabel('P [W]');
    subtitle(['altitude h = ',num2str(h(i)), 'm']);
    legend('P_p_a_r','P_i_n_d','P_t_o_t');
     grid on;

     figure
     plot(Vinf,Ptot_rp,'k-.',Vinf,Ptot_rc,'k--
',Vinf,P_ausil,'k:',Vinf,Ptot_request(j,:),'k-',Vinf,Pavaiable(j,:),'.-k');
     hold on;
     xlabel('V_∞ [m/s]'); ylabel('P [W]'); title('Total Required Power in forward
flight');
     subtitle(['altitude h = ',num2str(h(i)), 'm']);
     legend('P_m_a_i_n _r_o_t_o_r.','P_t_a_i_l
_r_o_t_o_r','P_a_u_x','P_t_o_t','P_a_v_a_i');
     grid on

    end
 end

   figure
    plot(Vinf,Ptot_request(j,:),'.-k');
    xlabel('V_∞ [m/s]'); ylabel('P [W]');
    subtitle(['altitude h = ',num2str(h(i)), 'm']);
    hold on;
    plot(Vinf,Pavaiable(j,:),'k');
    assey = linspace(0,Ptot_request(end),num);
    plot(V_NE*ones(1,num),assey,'k-.');
    plot(V_BE*ones(1,num),assey,'k--');
    plot(V_BR*ones(1,num),assey,'k');
    legend('P_t_o_t','P_a_v_a_i','V_N_E','V_B_E','V_B_R');

 % Total required power  in forward flight at different WTO
    figure
      plot(Vinf, Ptot_request(1,:), 'k- ',...
      Vinf, Ptot_request(2,:), 'k--',...
      Vinf, Ptot_request(3,:), 'k-.',...
      Vinf, Pavaiable(j,:)  , '.-k ');

    title('Total required power in forward flight at different W_T_O')
    subtitle(['altitude h = ',num2str(h(i)), 'm']);
    xlabel('V_∞ [m/s]'); ylabel('P [W]');
    legend('75% WTO',...
           '90% WTO',...
            'WTO',...
            'P_a_v_a_i_l_a_b_l_e');

    grid on;
% Rate of climb, fastest climb speed and maximum climbing angle at different WTO
% and different altitude.

[RC(1,:),Vy(i,1),RC_rapid(i,1),Vx(i,1),gamma_ripid(i,1)] = RateOfClimb( v_WTO(j),
Ptot_request(1,:),Pavaiable(1,:),Vinf);


    [RC(2,:),Vy(i,2),RC_rapid(i,2),Vx(i,2),gamma_ripid(i,2)] = RateOfClimb( v_WTO(j),
Ptot_request(2,:),Pavaiable(1,:),Vinf);
```

```
    [RC(3,:),Vy(i,3),RC_rapid(i,3),Vx(i,3),gamma_ripid(i,3)] = RateOfClimb( v_WTO(j),
Ptot_request(3,:),Pavaiable(1,:),Vinf);

       figure

    plot(Vinf, RC(1,:), 'k- ',...
         Vinf, RC(2,:), 'k--',...
         Vinf, RC(3,:), 'k-.');
    title('Rate of climb RC at different W_T_O')
    subtitle(['altitude h = ',num2str(h(i)), 'm']);
    xlabel('V_∞ [m/s]'); ylabel('RC [m/s]');
    legend(['75% Wto'],...
           ['90% Wto'],...
           ['Wto']);
    grid on;
end
 % table in excel with the value of RC at different weight and altitude
    % -----------------------------------------------------------------
    Testi = {'h = 0m','h = 1000m''m','h = 1800m'};
    Tabella = table(Vy(1,:)',Vy(2,:)',Vy(3,:)', 'VariableNames',Testi);
    writetable(Tabella,'Vinf - Salita Rapida.xlsx');

    Testi = {'h = 0m','h = 1000m''m','h = 1800m'};
    Tabella = table(RC_rapid(1,:)',RC_rapid(2,:)',RC_rapid(3,:)', 'VariableNames',Testi);
    writetable(Tabella,'RC - Salita Ripida.xlsx');


    Testi = {'h = 0m','h = 1000m''m','h = 1800m'};
    Tabella = table(Vx(1,:)',Vx(2,:)',Vx(3,:)', 'VariableNames',Testi);
    writetable(Tabella,'Vinf - Salita Ripida.xlsx');
```

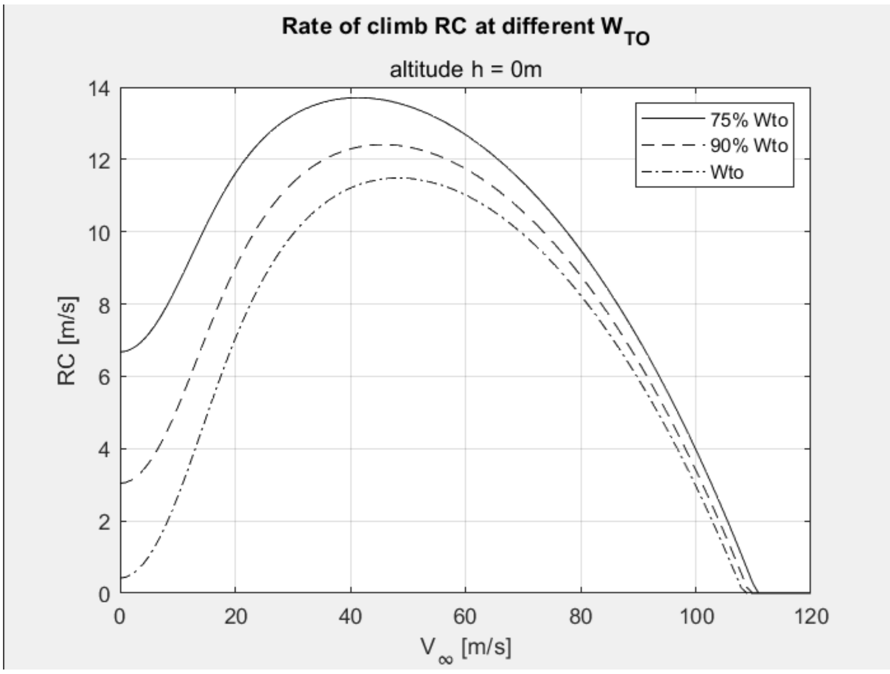

Figura 1.2: Rate of climb at different weights at Sea Level for the helicopter Sykorsky UH-60A.

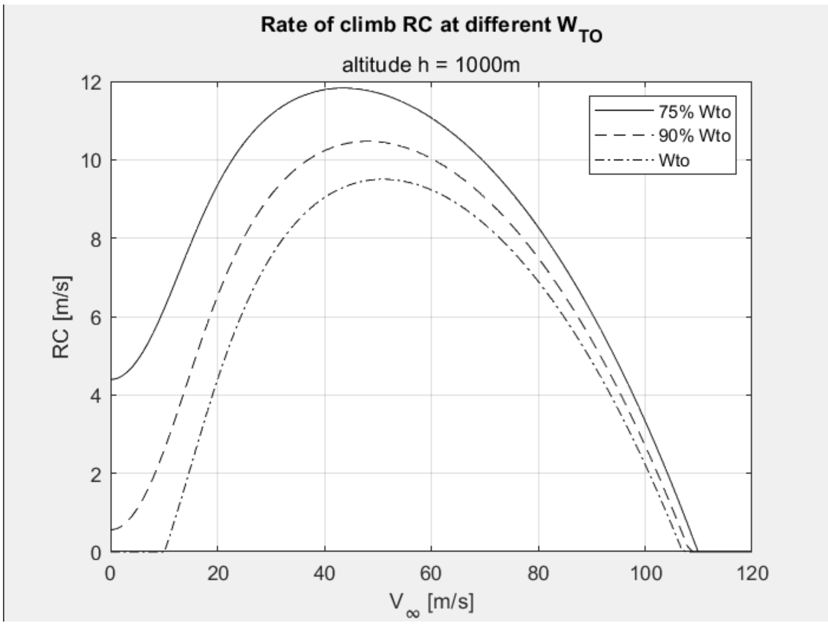

Figura 1.3: Rate of climb at different weights at 1000m for the helicopter Sykorsky UH-60A.

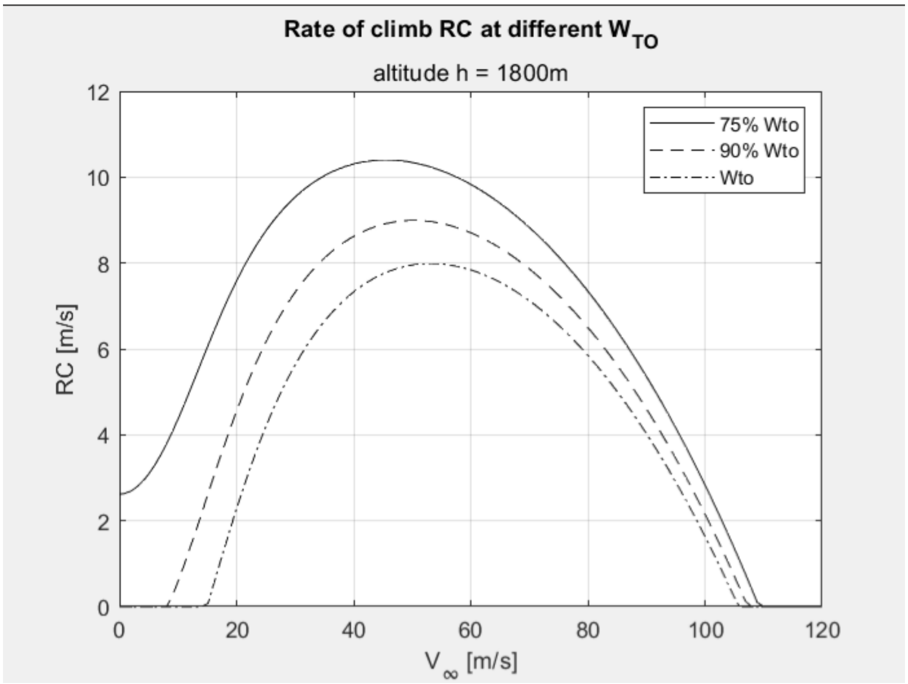

Figura 1.4: Rate of climb at different weights at 1800m for the helicopter Sykorsky UH-60A.

h = 0m	h = 1000m'm	h = 1800m
13,708277	11,8272705	10,4009325
12,4103886	10,4697231	8,99230462
11,4867618	9,50240863	7,98867904

Figura 1.5: Table in excel with the value of RC at different weights (75%Wto, 90%Wto, Wto) and altitudes (SL, 1000m, 1800m) for the helicopter Sykorsky UH-60A.

It can be observed that the rate of climb decreases with increasing altitude and weight; in fact, at fixed weight and with increasing altitude there is a reduction in available power, while at fixed altitude there is an increase in required power with weight. In both cases the difference at first member of (1.1) decreases and consequently there is a reduction in the rate of climb.

5 Bibliography

[1] aa 2022-2023 Didattica integrativa AAR Federico II Di Giorgio.pdf