analysis.R

sam

2021-03-13

```r
# Propeller analysis
# Script created by Sam Hince
# 01/11/2021

library(varhandle)
library(rjson)
library(caTools)
library(ggplot2)

rm(list = ls())

##########################################################################

# nomenclature:
# V = velocity of aircraft
# phi = angle
# Omega = angular
# B = number of blade
# r = radius along blade

##########################################################################

convergence_minimum <- 0.00001
feathering <- "none" # thrust, power, none

##########################################################################

## read in data from json
setwd("/home/sam/Documents/classGitRepos/MAE195")
geom <- fromJSON(file = './propSpecs/Cessna150.json') # P51_Mustang.json DesignOutput.json
coef <- read.csv(file = './propSpecs/NACA4415_RN500K_NCRIT9.csv', header = TRUE)

##########################################################################

## calculate some constants
mu <- geom$alt$kinematicViscosity * geom$alt$density   # N s/m^2 dynamic viscosity of the fluid
rho <- geom$alt$density                                # kg/m^3 density of air
B <- geom$blades                                       # number of blades
R <- geom$diameter / 2                                 # radius along the prop
V <- geom$velocity                                     # m / s volocity
Omega <- (2 * pi * geom$RPM) / 60                      # rad / s angular velocity of the propeller
```

```
################################################################################

## ass-umptions
beta <- 20 * (pi / 180) # blade angle is this given???

################################################################################

# equation 1:
eqn_phi <- function(V, a, Omega, r, aprime){
    phi <- atan2((V*(1+a)), (Omega*r*(1-aprime))) # should this be atan2?
    return(phi)
}

eqn_phi_estimate <- function(V, Omega, r){
    phi <- atan2(V, (Omega*r)) # initial phi condition (step 1)
    return(phi)
}

# quations 2:
eqn_alpha <- function(beta, phi){
    alpha <- beta - phi
    return(alpha)
}

eqn_W <- function(V, a, phi){
    W <- (V * (1 + a)) / sin(phi)
    return(W)
}

eqn_Re <- function(rho, W, c, mu){
    Re <- rho * W * (c / mu)
    return(Re)
}

# equation 3:
eqn_Cx <- function(Cl, Cd, phi){
    Cx <- (Cl * sin(phi)) + (Cd * cos(phi))
    return(Cx)
}

eqn_Cy <- function(Cl, Cd, phi){
    Cy <- (Cl * cos(phi)) - (Cd * sin(phi))
    return(Cy)
}

# equation 4:
eqn_a <- function(sigma, varF, Cy, phi){
    a <- ((sigma/(4*varF))*(Cy/(sin(phi)^2))) / (1-(sigma/(4*varF)*(Cy/(sin(phi)^2))))
    return(a)
}

eqn_aprime <- function(sigma, varF, Cx, phi){
    aprime <- ((sigma/(4*varF))*(Cx/(sin(phi)*cos(phi)))) / (1+(sigma/(4*varF)*(Cx/(sin(phi)*cos(phi)))
```

```
    return(aprime)
}

############################################################################

### complex plotting loop ###
#pl_df <- data.frame()
#og_thrust <- geom$thrust
#for(i in seq(1,10)){
#  geom$thrust <- og_thrust * (1 + (i * 0.05))

#pl_df <- data.frame()
#for(i in seq(1,30)){
#  geom$RPM <- geom$RPM + 50
#  Omega <- (2 * pi * geom$RPM) / 60

#pl_df <- data.frame()
#V <- V - 40
#og_thrust <- geom$thrust
#for(i in seq(1,10)){
#  V <- V + 10

#pl_df <- data.frame()
#og_B <- B
#for(i in seq(1,10)){
#  B <- og_B + i
#  geom$blades <- og_B + i

  keep_feathering <- TRUE
  total_d_beta <- 0
  while(keep_feathering){ # feathering loop

    df <- data.frame()

    for (station in 1:length(geom$radialStation)){
        #separate our values for this loop
        r <- geom$radialStation[station]
        Xi <- r/R
        c <- geom$chord[station]
        beta <- geom$beta[station] * (pi/180) # convery to rad

        # correction for final blade station:
        if(Xi >= 1){
            Xi <- 1 - 1e-15
        }

        #print(sprintf("Blade station: %g", r))

        #step 1
        # initial assumptions:
        phi <- eqn_phi_estimate(V, Omega, r)
        a <- 0
        aprime <- 0
```

```
    convergent <- FALSE
    loops_to_converge <- 0
    while(convergent == FALSE){
        #step 2
        alpha <- eqn_alpha(beta, phi)
        W <- eqn_W(V, a, phi)
        Re <- eqn_Re(rho, W, c, mu)

        #step 3
        alpha_degrees <- alpha * (180/pi)
        Cl <- approx(x = coef$ALPHA, y = coef$CL, xout = alpha_degrees, method="linear")$y
        Cd <- approx(x = coef$ALPHA, y = coef$CD, xout = alpha_degrees, method="linear")$y

        #step 4
        Cx <- eqn_Cx(Cl, Cd, phi)
        Cy <- eqn_Cy(Cl, Cd, phi)

        #step 5
        phit <- atan((Xi)*tan(phi))
        f <- (B/2)*((1-(Xi)) / (sin(phit)))
        varF <- (2/pi) * atan((exp(2*f)-1)^(1/2))

        #step 6
        sigma <- (B*c)/(2*pi*r) # local solidity
        a <- eqn_a(sigma, varF, Cy, phi)
        aprime <- eqn_aprime(sigma, varF, Cx, phi)

        # corrections for finite tip chord:
        if((abs(a) > .7) || (abs(aprime) > .7)){
            aprime = 0.4
        }

        #step 7
        phi_new <- eqn_phi(V, a, Omega, r, aprime)

        #step 8
        percent_change <- (abs(phi - phi_new)/phi)

        if(percent_change < convergence_minimum){   # if the percent change has decreased enough
            convergent <- TRUE                      # then assume we have reached convergence
            #print(sprintf("Phi converged in %g loops", loops_to_converge))
        } else {                                    # otherwise increment phi
            phi <- phi + (0.4 * (phi_new - phi))    # 0.4 is variable, recopmended value by liebeck
            loops_to_converge <- loops_to_converge + 1
        }
    }

    #record data
    df <- rbind(df, data.frame(station, r, c, beta * (180/pi), alpha_degrees, phi * (180/pi), Re / 

}

#reformat data
```

```
colnames(df) <- c("station", "r", "c", "beta", "alpha", "phi", "Re", "a", "aprime", "f", "F", "W",
#print(df)

#step 9
dr <- geom$radialStation[2]-geom$radialStation[1]
n <- geom$RPM / 60

#Ct:
coef_term <- (1/(rho * (n^2) * ((2*R)^4)))

integral <- 0
for(station in 1:(length(geom$radialStation)-1)){
    #separate our values for this loop
    c <- geom$chord[station]
    W <- df$W[station]
    Cy <- df$Cy[station]

    d <- ((1/2) * rho * (W^2) * B * c * Cy * dr)
    integral <- integral + d
}

thrust <- integral
Ct <-  integral * coef_term

#Cp:
coef_term <- (1/(rho * (n^3) * ((2*R)^5)))

integral <- 0
for(station in 1:(length(geom$radialStation)-1)){
    #separate our values for this loop
    r <- geom$radialStation[station] #df$r[station]
    c <- geom$chord[station]
    W <- df$W[station]
    Cx <- df$Cx[station]

    d <- ((1/2) * rho * (W^2) * B * c * Cx * Omega * r * dr) # Omega missing in the notes
    integral <- integral + d
}

power <- integral / 550
Cp <- integral * coef_term

advance_ratio <- V / (n * geom$diameter) # could use geom$J
efficiency <- Ct * advance_ratio / Cp

solidity <- (geom$blades * trapz(geom$radialStation, geom$chord)) / (pi * ((geom$diameter/2)^2))

### feathering stuff ###
if(feathering == "thrust"){
  dif_thrust <- geom$thrust - thrust
  delta <- (dif_thrust / abs(dif_thrust)) * 0.01
  print("changing by thrust")
  geom$beta <- geom$beta + delta
```

```r
      total_d_beta <- total_d_beta + delta

      if((abs(dif_thrust) / geom$thrust) > 0.01){
        keep_feathering <- TRUE
      }else{
        keep_feathering <- FALSE
      }

    }else if(feathering == "power"){
      dif_power <- geom$power - power
      delta <- (dif_power / abs(dif_power)) * 0.01
      print("changing by power")
      geom$beta <- geom$beta + delta
      total_d_beta <- total_d_beta + delta

      if((abs(dif_power) / geom$power) > 0.01){
        keep_feathering <- TRUE
      }else{
        keep_feathering <- FALSE
      }

    }else{
      break
    }
  }

  ### print output ###
  print((sprintf("Cp: %g", Cp)))
```

```
## [1] "Cp: 0.039485"
```

```r
  print((sprintf("Ct: %g", Ct)))
```

```
## [1] "Ct: 0.0492479"
```

```r
  print((sprintf("Efficiency: %g", efficiency)))
```

```
## [1] "Efficiency: 0.874869"
```

```r
  print((sprintf("Advance Ratio: %g", advance_ratio)))
```

```
## [1] "Advance Ratio: 0.701435"
```

```r
  print((sprintf("Power (Hp): %g", power)))
```

```
## [1] "Power (Hp): 68.6464"
```

```r
  print((sprintf("Thrust (lbs): %g", thrust)))
```

```
## [1] "Thrust (lbs): 204.743"
```

```r
print((sprintf("RPM: %g", geom$RPM)))
```

```
## [1] "RPM: 2400"
```

```r
print((sprintf("Solidity: %g", solidity)))
```

```
## [1] "Solidity: 0.0577591"
```

```r
minidf <- data.frame(df$station, df$c, df$beta)
colnames(minidf) <- c("station", "chord", "beta")

print(minidf)
```

```
##    station  chord  beta
## 1        1 0.3353 56.42
## 2        2 0.3966 50.50
## 3        3 0.4325 45.48
## 4        4 0.4484 41.24
## 5        5 0.4501 37.64
## 6        6 0.4423 34.57
## 7        7 0.4285 31.94
## 8        8 0.4110 29.66
## 9        9 0.3913 27.68
## 10      10 0.3704 25.95
## 11      11 0.3487 24.42
## 12      12 0.3265 23.06
## 13      13 0.3040 21.85
## 14      14 0.2810 20.77
## 15      15 0.2572 19.79
## 16      16 0.2324 18.90
## 17      17 0.2059 18.10
## 18      18 0.1768 17.36
## 19      19 0.1433 16.69
## 20      20 0.1006 16.07
## 21      21 0.0000 15.50
```

```r
print((sprintf("Total change in beta: %g deg", total_d_beta)))
```

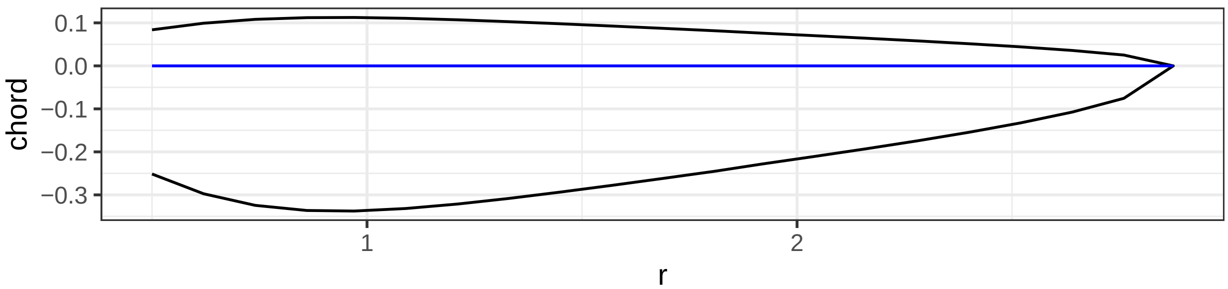
```
## [1] "Total change in beta: 0 deg"
```

```r
##########################################################################
# plotting code

prop_geom_le <- data.frame(chord = (df$c * (1/4)), r = df$r)
prop_geom_te <- data.frame(chord = (df$c * (-3/4)), r = df$r)
prop_geom_te <- prop_geom_te[seq(dim(prop_geom_te)[1],1),]

prop_geom <- rbind(prop_geom_le, prop_geom_te)

geom_plot <- ggplot(prop_geom, aes(x = r, y = chord)) + geom_path() + coord_fixed() + theme_bw() +
  geom_line(data = data.frame(chord = rep(0, length(df$r)), r = df$r), colour = "blue")
print(geom_plot)
```




```
  ##########################################################################

#  #record
#  pl_df <- rbind(pl_df, data.frame(Cp, Ct, eta = efficiency, J = advance_ratio, B = B))
#  pl_df <- rbind(pl_df, data.frame(T = geom$thrust, J = advance_ratio, velocity = V, degrees = total_d
#
#} # end advanced plotting loop

#coef <- 6
#pl <- ggplot(pl_df, aes(x = B)) +
#  geom_path(aes(y = Cp, colour = "Cp")) +
#  geom_point(aes(y = Cp, colour = "Cp")) +
#  geom_path(aes(y = Ct, colour = "Ct")) +
#  geom_point(aes(y = Ct, colour = "Ct")) +
#  geom_path(aes(y = eta/coef, colour = "eta")) +
#  geom_point(aes(y = eta/coef, colour = "eta")) +
#  scale_y_continuous(
#    # Features of the first axis
#    name = "Cp, Ct",

#    # Add a second axis and specify its features
#    sec.axis = sec_axis(~.*coef, name="Eta")) +
#  scale_colour_manual("",
#                          breaks = c("Cp", "Ct", "eta"),
#                          values = c("blue", "red", "green")) +
#  theme_bw()
```

```
#print(pl)

#pl <- ggplot(pl_df, aes(x = J, y = degrees)) +
#  geom_path() +
#  geom_point() +
#  #ggtitle("Feathering with Colocity") + # for the main title
#  xlab("J") + # for the x axis label
#  ylab("Feathing angle") + # for the y axis label
#  theme_bw()
#print(pl)
```