# Sensitivity Analysis of the Empirical Model

The following is a sensitivity analysis for the empirical model for propeller noise taken from Chapter 12 of the textbook “Elements of Aviation Acoustics” by G.J.J Ruijgrok. The propeller noise equation is given as:

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| --- | --- |
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# Input Identification of Regression Analysis Based Sound Models

Following table identifies the different inputs to the several flyover sound models delineated in the technical study “The Development of a Flyover Noise Prediction Technique Using Multiple Linear Regression Analysis” by Cessna Aircraft Co.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Model Number:** | | **1** | **2** | **3** | **4** | **5** | **7** | **8** | **9** | **10** |
| **Parameter** | **Unit** |  |  |  |  |  |  |  |  |  |
| Helical Mach | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Shaft HP | Hp |  |  |  |  |  | ✓ | ✓ | ✓ | ✓ |
| Helical Mach Squared | - |  |  |  |  |  | ✓ |  |  |  |
| Two or Three Blades ? | - |  |  | ✓ |  |  | ✓ | ✓ |  | ✓ |
| Turbocharger Enabled? | - |  |  |  |  |  | ✓ | ✓ |  | ✓ |
| Single or Twin engine? | - |  |  |  |  |  | ✓ |  |  | ✓ |

# Codes for both Models

## Empirical Model

clc;clear;close all

%For this code, let us use the data from Chapter 14 examples of Gudmundson

%The model has been taken from Ref 18 - "Elements of aviation Acoustics"

%Starting with the piston engine noise:

n = 2600;%engine rotational speed in RPM

N = 4;%number of cylinders

f\_c = n/120;%cylinder firing frequency

f\_e = (N\*n)/120;%exhaust firing frequency

% According to Reference 61, the overall A-weighted level of the exhaust noise

% of an unmuffled piston engine at 150 m sideline can be estimated by:

P\_br = 310\*745.7;%engine shaft power, watts

L\_A = 8 + (14\*log10(P\_br)) %dBA

%Using data in Gudmundson - An airplane is powered by a two-bladed propeller

%whose diameter is 76 inches is driven by a 310 BHP engine

%Then moving on to propeller noise:

% For the prediction of far-field propeller noise, the following expres sion for the

% maximum sound pressure level can be used:

B = 3;%number of blades per propeller

n\_p = 2600;%propeller rotational speed (rpm)

D = 1.9304;%propeller diameter (m)

r = 50;%distance from propeller (m)

c = 340;%speed of sound(m/s)

M\_t = (pi\*D\*n\_p)/(60\*c);%tip mach number

SPL\_max = 83.4 + (15.3\*log10(P\_br)) - (20\*log10(D)) + (38.5\*M\_t) + ...

(-3\*(B - 2)) + (10\*log10(N)) - (20\*log10(r))

%Sensitivity Analysis for the propeller model

%First we will vary each input parameter indvidually to check its impact on

%the sound level while keeping the other inputs constant.

%Sensitivity to Number of Blades

figure(1)

B\_set = [2, 3, 4, 5, 6];

SPL\_max\_B = 83.4 + (15.3.\*log10(P\_br)) - (20.\*log10(D)) + (38.5.\*M\_t) + ...

(-3.\*(B\_set - 2)) + (10.\*log10(N)) - (20.\*log10(r))

plot(B\_set,SPL\_max\_B,'r','LineWidth',2);grid on

xlabel('Number of blades');ylabel('SPL\_{max} (dBA)');title('SPL variation with No. of Blades')

%Sensitivity to Engine Horse Power

figure(2)

P\_br\_set = [200:10:400].\*745.7;%watts

SPL\_max\_P\_br = 83.4 + (15.3.\*log10(P\_br\_set)) - (20.\*log10(D)) + (38.5.\*M\_t) + ...

(-3.\*(B - 2)) + (10.\*log10(N)) - (20.\*log10(r))

plot(P\_br\_set,SPL\_max\_P\_br,'g','LineWidth',2);grid on

xlabel('engine shaft power (watts)');ylabel('SPL\_{max} (dBA)');title('SPL variation with engine shaft power')

%Sensitivity to Propeller RPM i.e. tip mach

figure(3)

n\_p\_set = 1000:100:3000

M\_t\_set = (pi.\*D.\*n\_p\_set)./(60.\*c);%tip mach number

SPL\_max\_n\_p = 83.4 + (15.3.\*log10(P\_br)) - (20.\*log10(D)) + (38.5.\*M\_t\_set) + ...

(-3.\*(B - 2)) + (10.\*log10(N)) - (20.\*log10(r))

plot(n\_p\_set,SPL\_max\_n\_p,'b','LineWidth',2);grid on

xlabel('Propeller RPM');ylabel('SPL\_{max} (dBA)');title('SPL variation with propeller RPM')

%Sensitivity to Propeller Diameter i.e. also affects tip mach

figure(4)

D\_set = 0.5:0.1:2;%propeller diameter (m)

M\_t\_set\_2 = (pi.\*D\_set.\*n\_p)./(60.\*c);%tip mach number

SPL\_max\_D = 83.4 + (15.3.\*log10(P\_br)) - (20.\*log10(D\_set)) + (38.5.\*M\_t\_set\_2) + ...

(-3.\*(B - 2)) + (10.\*log10(N)) - (20.\*log10(r))

plot(D\_set,SPL\_max\_D,'c','LineWidth',2);grid on

xlabel('Propeller Diameter (m)');ylabel('SPL\_{max} (dBA)');title('SPL variation with propeller diameter')

%Sensitivity to distance From Propeller

figure(5)

r\_set = 0:10:100;%distance from propeller (m)

SPL\_max\_r = 83.4 + (15.3.\*log10(P\_br)) - (20.\*log10(D)) + (38.5.\*M\_t) + ...

(-3.\*(B - 2)) + (10.\*log10(N)) - (20.\*log10(r\_set))

plot(r\_set,SPL\_max\_r,'k','LineWidth',2);grid on

xlabel('distance from propeller (m)');ylabel('SPL\_{max} (dBA)');title('SPL variation with distance from propeller')

## Regression Models

%Following are the regression based models from the paper:

% "The Development of a Flyover Noise Prediction Technique Using Multiple

% Linear Regression Analysis"

clc;clear variables;close all

%MODEL # 1 - (Single Engine Aircraft)

X\_1 = 0.79;%Helical Mach

Y\_1 = 12.7506 + (75.6219\*X\_1);%dBA

%MODEL # 2 - (Twin Engine Aircraft)

X\_2 = 0.78;%Helical Mach

Y\_2 = 25.99 + (65.0586\*X\_2);%dBA

%MODEL # 3 - (Single and Twin Engine)

X\_3\_1 = 0.78;%Helical Mach

X\_3\_2 = 0;% 0 for single and 1 for double prop

Y\_3 = 13.2314 + (75.0445\*X\_3\_1) + (4.3295\*X\_3\_2);%dBA

%MODEL # 4 - (Single Engine Aircraft)

X\_4 = 0.78;%Helical Mach

Y\_4 = 86.7697 + (137.8972\*X\_4);%dBA

%MODEL # 5 - (Single Engine Aircraft)

X\_5 = 0.78;%Helical Mach

Y\_5 = 60.8837 + (0.00481\*X\_5);%dBA

%MODEL # 6 - ILLEGIBLE

%MODEL # 7 - (Sing and Twin Engine Aircraft)

X\_7\_1 = 250;%BHP

X\_7\_2 = 0.78;%Helical Mach

X\_7\_3 = X\_7\_2^2;%Helical Mach Squared

X\_7\_4 = 0;%0 for 2 blade, 1 for 3 blade

X\_7\_5 = 0;%0 for non-turbo, 1 for turbo

X\_7\_6 = 0;%0 for single engine, 1 for twin engine

Y\_7 = 31.3920 + (0.0067\*X\_7\_1) + (46.1576\*X\_7\_2) + (4.2376\*X\_7\_3) + ...

(2.5981\*X\_7\_4) + (0.2577\*X\_7\_5) + (2.6106\*X\_7\_6);

%MODEL # 8 - (Single Engine Aircraft)

X\_8\_1 = 250;%BHP

X\_8\_2 = 0.78;%Helical Mach

X\_8\_3 = 0;%0 for 2 blade, 1 for 3 blade

X\_8\_4 = 0;%0 for non-turbo, 1 for turbo

Y\_8 = 30.5646 + (0.00942\*X\_8\_1) + (49.9636\*X\_8\_2) + (2.4494\*X\_8\_3) + (0.4552\*X\_8\_4);

%MODEL # 9 - (Twin Engine Aircraft)

X\_9\_1 = 250;%BHP

X\_9\_2 = 0.78;%Helical Mach

Y\_9 = 5.2566 + (0.01428\*X\_9\_1) + (84.2969\*X\_9\_2);

%MODEL # 10 -

X\_10\_1 = 250;%BHP

X\_10\_2 = 0.78;%Helical Mach

X\_10\_3 = 0;%0 for 2 blade, 1 for 3 blade

X\_10\_4 = 0;%0 for non-turbo, 1 for turbo

X\_10\_5 = 0;%0 for single engine, 1 for twin engine

Y\_10 = 28.8194 + (0.00678\*X\_10\_1) + (52.6543\*X\_10\_2) + (2.8333\*X\_10\_3)...

+ (0.2603\*X\_10\_4) + (2.5742\*X\_10\_5);