DLR-IB-FT-BS-2026-10

# HQ-Tools - An Add-On to FITLAB for Handling Qualities Analysis

Interner Bericht

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German Aerospace Center

Institute Report
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**Availability/Distribution: I, internally and externally unlimited distribution**

Braunschweig, 30 January 2026

[redacted]

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**Document Identification:**

| | |
|---|---|
| Report number . . . . . | DLR-IB-FT-BS-2026-10 |
| Title . . . . . . . . . . . . | HQ-Tools - An Add-On to FITLAB for Handling Qualities Analysis |
| Author(s) . . . . . . . . . | Susanne Seher-Weiß |
| Filename . . . . . . . . . | HQtools.tex |
| Last saved on . . . . . . | 30th January 2026 |

# Contents

# Nomenclature

| Symbol | Channel[a] | Description |
|---|---|---|
| $A$ | | amplitude |
| $h$ | | height |
| $\dot{h}$ | Hdot | altitude rate |
| $K$ | | gain |
| $n_z$ | Nz | normal acceleration |
| $P$ | | period |
| $p$ | P | roll rate |
| $Q$ | Torque | torque |
| $q$ | Q | pitch rate |
| $r$ | R | yaw rate |
| $r^2$ | | coefficient of determination |
| $s$ | | Laplace variable |
| $T$ | | time constant |
| $T_2$ | | time to double |
| $t$ | time | time |
| $\beta$ | Beta | sideslip angle |
| $\Delta$ | | difference between two values |
| $\delta$ | | logarithmic decrement |
| $\delta_0$ | Dcol | collective control input |
| $\delta_p$ | Dped | pedal control input |
| $\delta_x$ | Dlon | longitudinal cyclic control input |
| $\delta_y$ | Dlat | lateral cyclic control input |
| $\epsilon$ | | error |
| $\Phi$ | | phase angle |
| $\phi$ | Phi | bank angle |
| $\phi_i$ | | amplitude of the $i$-th bank angle peak |
| $\theta$ | Theta | pitch angle |
| $\sigma$ | | standard deviation |
| $\tau$ | | time delay |
| $\tau_p$ | | phase delay |
| $\omega$ | | frequency |
| $\omega_{180}$ | | neutral stability frequency |
| $\omega_{BW}$ | | bandwidth frequency |
| $\omega_{CO}$ | | cutoff frequency |
| $\omega_n$ | | natural frequency |
| $\psi$ | Psi | heading angle |
| $\psi_\beta$ | | Dutch roll phase angle |
| $\zeta$ | | damping ratio |

[a] Name of the corresponding data channel in the example datasets.

Subscripts

| | |
|---|---|
| $d$ | Dutch roll |
| $eq$ | equivalent value |
| $est$ | estimated value |
| $mean$ | mean value |
| $min$ | minimum value |
| $pk$ | peak value |

Abbreviations

| | |
|---|---|
| ACT/FHS | Active Control Technology/Flying Helicopter Simulator |
| BW | Bandwidth |
| GUI | Graphical User Interface |
| HQ | Handling Qualities |
| MTE | Mission Task Element |
| RMS | Root Mean Square value |
| TAT | Target Aquisition and Tracking |
| TF | Transfer Function models with numerator and denominator |
| UCE | Usable Cue Environment |
| ZPK | Zero-Pole-Gain models |

# 1 Introduction

Helicopter handling qualities requirements are specified in the military detail specification MIL-DTL-32472 [1] which is based on the Aeronautical Design Standard ADS-33E-PRF [2] and revisions proposed in [3]. These specifications consist of quantitative requirements that evaluate the response to prescribed inputs and qualitative criteria that are implemented through a set of demonstration maneuvers or Mission Task Elements.

The quantitative criteria are divided into small-, mid- and large-amplitude as well as into short-term and mid-term criteria. Requirements are specified for the on-axis responses in pitch, roll, yaw and heave as well as for the inter-axis coupling responses. Separate requirements exist for the hover/low speed regime (<45 knots) and the forward flight regime. For helicopters and compound configurations that operate in the high-speed regime, HQ (handling qualities) criteria from the fixed-wing specification MIL-STD-1797B [4] are often applied.

A more mission oriented approach to helicopter handling qualities is taken by the Mission Task Elements (MTEs). The ADS-33 contains 23 MTEs that are supposed to cover the main tasks that occur during operation (e.g. hover, acceleration/deceleration, various turns, landing). Each MTE has a definite start and finish as well as prescribed temporal and spatial performance requirements. The limits for desired and adequate performance of each MTE depend on the rotorcraft category (attack, scout, utility, cargo) and the visual environment (good, degraded).

HQ-Tools is based on the toolbox HHQTools [5] and the software tool HAT (Handling qualities Analysis Tool) [6]. Recently, several fixed-wing HQ criteria were added. The HQ-Tools add-on to FitlabGui encompasses the functionality to evaluate the most important quantitative HQ criteria as well as some other HQ parameters. Furthermore, it allows to produce standardized plots for several of the MTE maneuvers.

This report describes only the HQ-Tools add-on to FitlabGui. For the other FitlabGui capabilities, the reader is referred to the FitlabGui documentation [7].

# 2 Usage

The HQ-Tools software is installed into a subdirectory named `hat_pcode` of the Fitlab directory. This directory has to be added to the MATLAB search path. Once this subdirectory exists, an additional menu named **HQ-Tools** appears on the main FitlabGui panel.

## 2.1 Data

Depending on the specific criterion, the quantitative criteria of HQ-Tools work on time domain and/or frequency response data. The MTE plots require time history data with special data channels as generated in ACT/FHS flight test and simulator runs once the corresponding MTE displays are active.

### 2.1.1 Time Domain Data

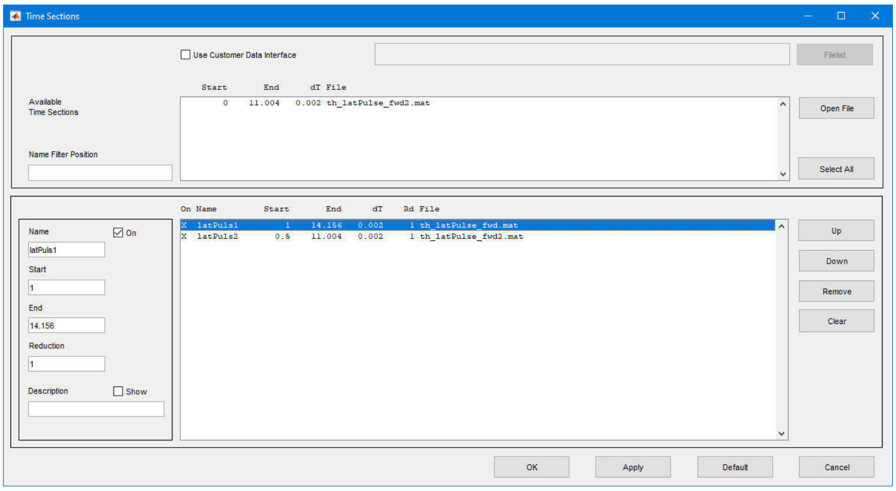


Figure 2.1: Selection of data files and time intervals

Time history data to be evaluated by HQ-Tools is loaded into FitlabGui via the **Load Time Sections from File** item from the **Data** menu of FitlabGui. A detailed description of loading time domain data into FitlabGui including the options and the supported data formats is found in the FitlabGui documentation [7]. All time intervals that are marked with **On** in the panel from figure 2.1 are available for evaluation in HQ-Tools.

If a simulation or identification with a model type that produces time history data (nonlinear, linear time domain as well as linear frequency domain or linear frequency response with additional simulation in the time domain, see [7]) has been performed in FitlabGui, the model outputs are also available for evaluation with the quantitative handling qualities criteria.

### 2.1.2 Frequency Domain Data

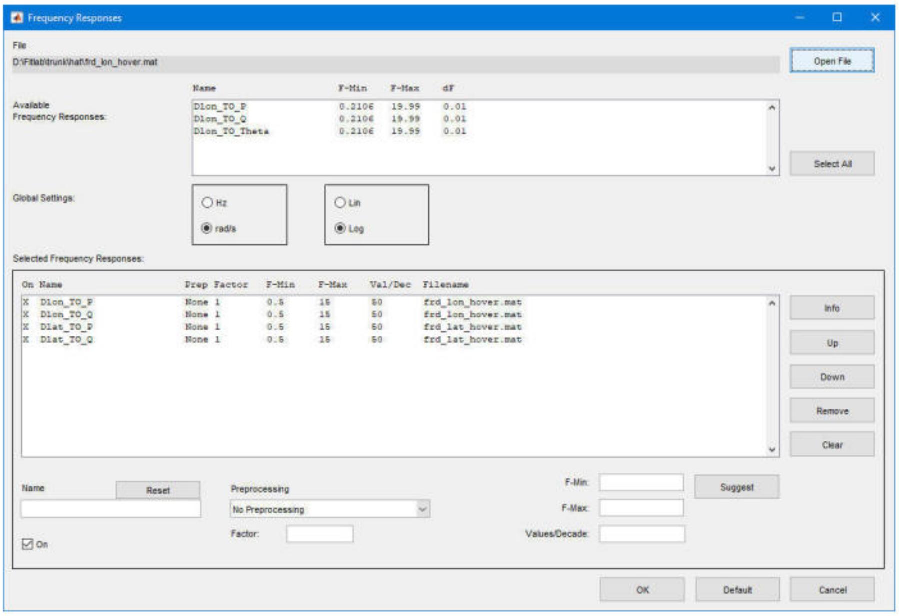

Figure 2.2: Selection of frequency responses from file

Frequency response data for use with HQ-Tools is loaded into FitlabGui via the **Load Frequency Responses from File** item of the **Data** menu. Frequency responses can be generated from time history data via the **Frequency Response Generation** item from the **Data** menu. Analytical transfer function models (of type TF or ZPK) can also be read into FitlabGui. Frequency response data for these analytical models is automatically generated for the frequency range specified in the panel from figure 2.2. A detailed description of generating frequency responses from time history data and the description of loading frequency response data in FitlabGui is found in [7].

All frequency responses that are marked with **On** in the panel from figure 2.2 are available for evaluation in HQ-Tools.

If a simulation or identification with the linear frequency response model type has been performed in FitlabGui, the model frequency responses are also available for evaluation with the quantitative handling qualities criteria.

## 2.2 Examples

HQ-Tools comes with a set of examples that can be used to try out the HQ criteria and MTE plots. The example data is a collection of simulated and flight test data from different configurations.

A set of FitlabGui projects named `HQtools_<criterion>_<extension>` allows for easy loading of the example data. Here, `<criterion>` stands for the name of the corresponding HQ criterion. For some criteria, more than one example is given. In this case `<extension>` specifies the speed (Hover or Fwd), axis (Pitch, Roll, Yaw), and/or time or frequency domain (TD, FD). FitlabGui projects are loaded into FitlabGui via the **Open** item from the **Project** menu (see [7]).

Within the examples, files named `th_<maneuver>` denote time history data for a maneuver of type `<maneuver>`. For the time history datasets that can be used with the quantitative criteria, the names of the data channels are listed in the nomenclature. The MTE example datasets need fixed channel names that are given in the description of the MTE plots in chapter 5.

Example files named `frd_<control>_<speed>` contain frequency response data for the control input `<control>` at the speed `<speed>`. All frequency responses are named `<input>_TO_<output>` where `<input>` and `<output>` denote the channel names of the corresponding control input and output signal channels.

A set of scripts named `script_<criterion>_<extension>` illustrates the use of the quantitative criteria outside of FitlabGui by implementing the corresponding examples in script form.

## 2.3 Script Usage

To enable HQ analysis also outside of FitlabGui, the routines that calculate the parameters for the quantitative criteria as well as the routines that plot these parameters and the corresponding HQ levels are provided as m-files.

The general calling structure for the calculation routines is

```
[CritPar] = HAT_<criterion>_Calc(data/frData,strings,TimeNr,options,...
            user,doPlot)
```

The input and output arguments are as follows:

| | |
|---|---|
| data | structure with time domain data, or |
| frData | structure with frequency response data |
| strings | structure with strings for labeling the plots (time domain only) |
| TimeNr | set to zero for script use (time domain only) |
| options | settings that are needed for the criterion and come from the corresponding panel when the routine is called from FitlabGui (e.g. Axis) |
| user | logical to switch user interaction on or off (default: on) |
| doPlot | logical to switch supporting plots on or off (default: on) |
| CritPar | calculated criterion parameters |

For more details and the exact arguments for each criterion, the user is referred to the corresponding example script and the header information of the individual calculation routine.

The general calling structure for the routines that generate the level plots is

```
[limit] = HAT_<criterion>_Level(options,CritPar,PlotOn,Source)
```

with the arguments

| | |
|---|---|
| options | settings that are needed for the criterion and come from the corresponding panel when the routine is called from FitlabGui (e.g. Axis) |
| CritPar | criterion parameters as determined from the corresponding Calc-routine |
| PlotOn | chooses which plots are generated, if several are available (e.g. for different agility levels) |
| Source | source of the limits, if several are available |

| | |
|---|---|
| `limit.caseStr` | if the criterion has limits for different cases (e.g. limited or moderate agility), the case for the corresponding limits is given |
| `limit.XL1` | x-coordinates of the level 1 limit |
| `limit.YL1` | y-coordinates of the level 1 limit |
| `limit.XL2` | x-coordinates of the level 2 limit |
| `limit.YL2` | y-coordinates of the level 2 limit |
| `limit.XL3` | x-coordinates of the level 3 limit (if available) |
| `limit.YL3` | y-coordinates of the level 3 limit (if available) |

If the routines for the level plots are called with an output argument, only the limits for the different HQ levels are returned and no plots are produced.

If the level plot routines are called without an output argument and with empty `CritPar`, no new figure is generated and only the level borders are drawn in the current (sub)figure with the corresponding title and axes labels.

More details and the exact arguments for each criterion can be found in the example scripts and the header information of the level plot routines.

# 3 Handling Qualities Criteria

HQ-Tools allows to evaluate the following quantitative handling qualities criteria that can be selected from the **HQ-Tools** menu of FitlabGui:

- Bandwidth, Disturbance Rejection, Gain/Phase Margin, Nichols Margins
- Dynamic Stability, Attitude Quickness, Large Amplitude, Spiral Stability
- Height Response, Flightpath Response to Pitch, Torque Response
- Pitch due to Collective, Yaw due to Collective, Pitch-Roll Coupling, Roll-Sideslip Coupling
- Pitch Attitude Dropback, Flightpath Bandwidth, Roll Performance

The first group of criteria pertains to all axes, the second group to the pitch, roll, and yaw motion and the third group to the vertical motion. The fourth criteria group encompasses the coupling criteria and the last group those fixed-wing criteria that have no rotorcraft equivalent.

The **Options** item from the **HQ-Tools** menu allows to specify a logfile for saving the results. If a logfile is specified, all numerical output from the evaluations listed above, that appears in the main FitlabGui window, is also written into this logfile. Additional output from subsequent calculations is always appended to the logfile (nothing is overwritten).

The panels for all of the criteria listed above have four buttons at the bottom labeled **Start**, **Default**, **Info**, and **Cancel**. The **Start** button initiates the calculations and plots for the current criterion. The **Default** button resets all fields in the panel to their default values. The **Info** button opens a separate window displaying some information about the criterion (aim, required data, parameters to be determined, implementation, references). The **Cancel** button closes the current panel and all plot windows corresponding to this criterion. All quantitative criteria are described in detail in the following sections.

## 3.1 Bandwidth

The bandwidth criterion addresses small-amplitude short-term attitude changes to control input. The criterion parameters bandwidth $\omega_{BW}$ and phase delay $\tau_p$ are determined from the frequency response of pitch (roll/yaw) attitude to longitudinal cyclic (lateral cyclic/pedal) input as defined in figure 6 of ADS-33 [2].

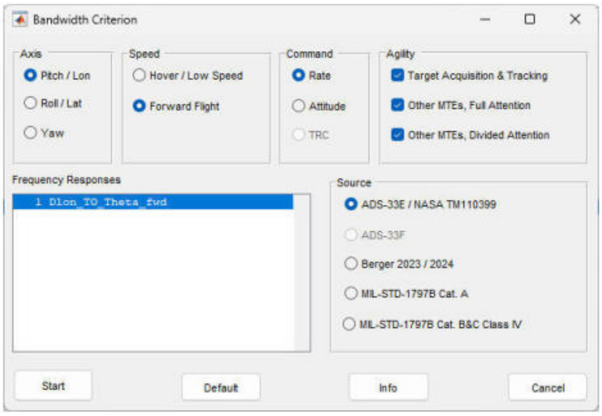


Figure 3.1: Bandwidth Criterion Panel

Figure 3.1 shows the panel for the bandwidth criterion in HQ-Tools. In the upper part, the user has to specify the current axis (pitch/lon, roll/lat, or yaw), the speed (hover / low speed or forward flight) and the command system type (rate or attitude or translational rate (TRC) command). On the right side, the user can specify the level(s) of agility, for which he wants the plots to be generated (not applicable for TRC).

In the lower left part, the frequency responses to be evaluated have to be selected as a subset of the currently active frequency responses (see section 2.1.2). In the lower right part, different sources of the HQ criterion boundaries can be chosen as alternatives to the default ADS-33E values. For the pitch axis, the proposed boundaries from the paper by Berger [8] or the boundaries from the fixed-wing criteria MIL-STD-1797B [4] for different aircraft categories can be chosen. If the yaw axis has been selected, the user has the option to use the proposed boundaries from ADS-33F [3] or the paper by Berger [9] instead of the ADS-33E values. If TRC has been chosen as command system type, only the longitudinal or lateral axis can be selected and the boundaries from [10] for hover are used.

After pressing the **Start** button, a bode plot appears and the user is asked, whether he wants the -180°-crossing that corresponds to the neutral stability frequency $\omega_{180}$ to be determined automatically or manually. For manual determination, each -180°-crossing found is in turn presented to the user and he must select whether this crossing is the correct one or if he wants to proceed to the next crossing. Once $\omega_{180}$ has been determined, the gain bandwidth $\omega_{BW_{gain}}$ (frequency at which the gain margin is 6 dB) and phase bandwidth $\omega_{BW_{phase}}$ (frequency at which the phase margin is 45°) are determined automatically. The bandwidth is then calculated via

$$\omega_{BW} = \begin{cases} \min\left(\omega_{BW_{gain}}, \omega_{BW_{phase}}\right) & \text{rate response system or TRC} \\ \omega_{BW_{phase}} & \text{attitude response system} \end{cases} \tag{3.1}$$

and the phase delay is determined from a linear fit of the phase curve between $\omega_{180}$ and $2\omega_{180}$

Once the bandwidth and time delay have been determined for all selected frequency responses, the numerical results are listed in the main FitlabGui window and, if activated, also in the logfile. In addition, plots corresponding to the selected agility level(s) appear that show the resulting phase delay versus bandwidth in comparison to the corresponding HQ levels (see figures 5, 9, 16, 17, and 22 from ADS-33E [2], figure 7 from ADS-33F [3], table A1 from [10], figure 41a from [4] or the respective papers from Berger).

For the script version without user interaction, the -180°-crossing is always detected automatically.

## 3.2 Disturbance Rejection

The disturbance rejection criterion evaluates the short term response to disturbance inputs. The disturbance rejection peak (DRP) and disturbance rejection bandwidth (DRB) are determined from the frequency response of attitude to disturbance input as defined in figure 32 of MIL-DTL-32742 [1].

Figure 3.2 shows the panel for the disturbance rejection criterion in HQ-Tools. In the upper part, the user has to specify the axis and in the lower part the frequency responses to be evaluated.

Upon pressing the **Start** button, a bode plot appears for each frequency response and the disturbance rejection peak and bandwidth are determined automatically and marked in the plot. A warning is displayed if no disturbance bandwidth was found.

Once the DRP and DRB have been determined for all selected frequency responses, the numerical results are listed in the main FitlabGui window and, if activated, also in the logfile. In addition, a plot shows the results in comparison to the corresponding HQ levels (see table 1 from ADS-33F [3]).

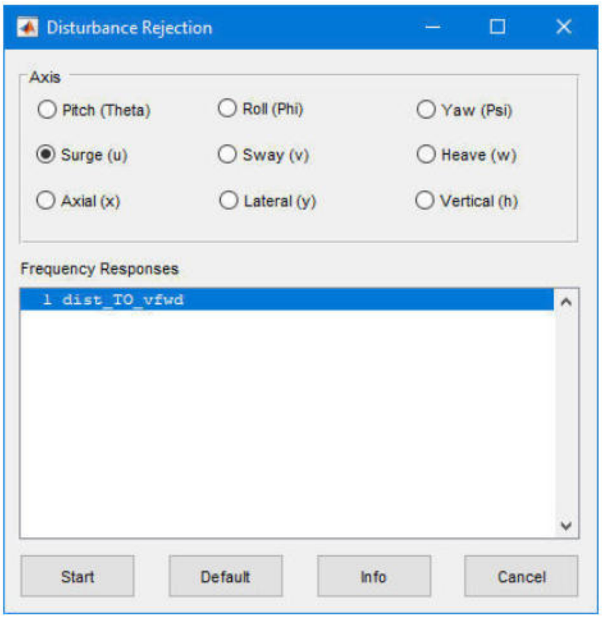


Figure 3.2: Disturbance Rejection Panel

## 3.3 Gain / Phase Margin

The gain and phase margins are essential for assessing the stability of a control system. They indicate how much gain or phase can change before the system becomes unstable.

Figure 3.3 shows the panel for the gain / phase margin calculation. The user has to select the broken loop frequency responses to be evaluated from the list of all available frequency responses. On the lower right of the panel, the axis for the evaluation has to be specified.

After pressing the **Start** button, the gain and phase margin as well as the corresponding crossover frequencies are calculated using the routine `margin` from the MATLAB Control System Toolbox. The minimum crossover frequency is equal to the phase crossover frequency.

The stability margins as well as the minimum crossover frequency are then plotted against the level boundaries from MIL-DTL-9490E [11].

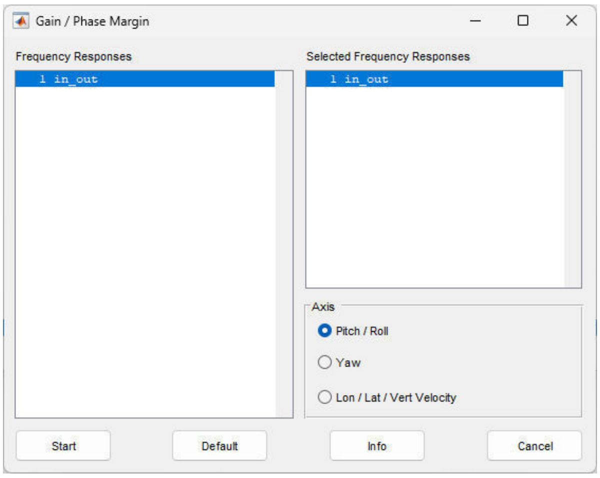


Figure 3.3: Gain / Phase Margin Panel

## 3.4 Nichols Margins

The Nichols margins are used to present robust boundaries for broken-loop gain and phase.

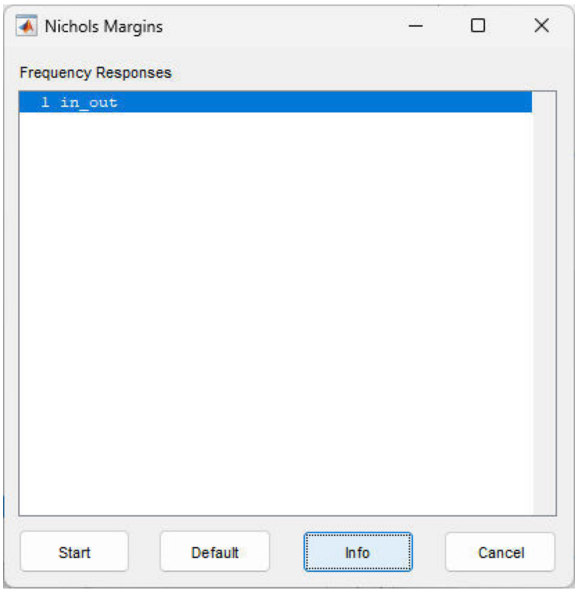


Figure 3.4: Nichols Margins Panel

Figure 3.4 shows corresponding the panel. The user has to only specify the frequency response to be plotted against the boundaries from [12]. No parameters are determined.

## 3.5 Dynamic Stability

The dynamic stability criterion is a classical stability criterion that examines mid-term small-amplitude attitude changes to control input. The criterion metrics are the natural frequency $\omega_n$ and damping ratio $\zeta$ of the oscillatory modes. The dynamic stability criterion is applicable at all frequencies below the bandwidth frequency in pitch and at all frequencies for the other axes and thus addresses the lower frequency modes of phugoid and Dutch roll.

The determination of the dynamic stability parameters from time history data is only possible when the phugoid and Dutch roll responses are separated which is usually only the case in forward flight. Then, the eigenmotions can be excited by a pulse or doublet in longitudinal cyclic (lateral cyclic, pedal) input and the natural frequency and damping ratio can be determined either by the logarithmic decrement method or by fitting a decreasing sinusoidal function to the response. If the response is of a step-response type, the peak overshoot method can be used.

For the logarithmic decrement method, the decrement $\delta$ of the oscillation is determined from the $n$ successive peaks (minima and maxima) $A_1, \ldots, A_n$ at time points $t_1, \ldots, t_n$ via

$$\delta = \frac{2}{n-2} \log \frac{|A_1| + |A_2|}{|A_{n-1}| + |A_n|} \tag{3.2}$$

The period is determined as $P = t_3 - t_1$ for case of evaluating three consecutive attitude peaks and via $P = (t_3 - t_1 + t_4 - t_2)/2$ for the case of five peaks.

The desired parameters $\omega_n$ and $\zeta$ are finally attained through

$$\omega_n = \sqrt{\xi_i^2 + \xi_r^2} \quad \text{with} \quad \xi_i = 2\pi/P,\ \xi_r = \delta/P \tag{3.3}$$

$$\zeta = \xi_r/\omega_n \tag{3.4}$$

For the second method, a decreasing sinusoidal function of the form

$$x = Ae^{-\zeta\omega_n(t-t_0)} \cos\left(\omega_n\sqrt{1-\zeta^2}(t-t_0)\right) \tag{3.5}$$

with parameters $A$, $t_0$, $\zeta$ and $\omega_n$ is fitted to the attitude time history.

For the peak overshoot method, it is assumed that the control input is applied at $t = 0$. If the peak response $y_{Pk}$ is reached at $t = t_{Pk}$ and $y_{SS}$ is the steady-state-value of the response, the overshoot $M_p$ with respect to the steady-state values is determined as

$M_p = (y_{Pk} - y_{SS})/y_{SS}$. The frequency and damping are then determined as

$$\zeta = \frac{-\ln M_p}{\sqrt{\pi^2 + \ln {M_p}^2}} \tag{3.6}$$

$$\omega_n = \pi/(t_p * \sqrt{1-\zeta^2}) \tag{3.7}$$

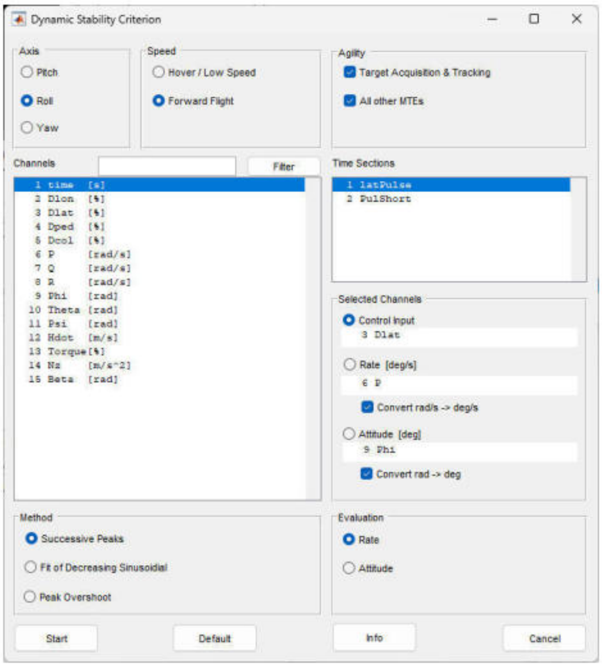


Figure 3.5: Dynamic Stability Criterion Panel

The panel for the dynamic stability criterion is shown in figure 3.5. In the upper part, the axis, the speed, and the level(s) of agility for which the plots are to be generated have to be specified. In the center of the panel, the time sections to be evaluated have to be specified on the right and the data channels for the control input and the corresponding rate and attitude responses have to be chosen from the list of all available data channels that is displayed on the left. The **Filter** field allows to search the data channels for channel names containing a certain filter string which makes searching for signals in huge data files easier. For angular rate and attitude angle, checkboxes are provided to convert the units from radians to degrees. In the lower part of the panel, the user has to select the evaluation method from **Successive Peaks** for the logarithmic decrement method, **Fit of Decreasing Sinusiodial**, or **Peak Overshoot**. Furthermore, the user has to select whether the **Rate** or the **Attitude** shall be used for the evaluation.

Once the user presses the **Start** button, a plot with control input, angular rate, and attitude angle appears for each selected time interval. If **Successive Peaks** has been selected as the evaluation method, the user has to mark three or five successive peaks (minima and maxima) in the attitude plot. With **Fit of Decreasing Sinusiodial** as the evaluation method, the user has to specify initial values for the model parameters in a separate window and then start the model fit. After the optimization, the result of the fit is plotted in comparison to the measured data. If the user is satisfied with the fit, pressing the **Continue** button leads to the next time interval. If not, the user can try to improve the fit by modifying the starting values. When using the model fit option, care has to be taken that the time interval to be evaluated contains only the free response to the control input.

Once the natural frequency and damping have been determined for all selected time sections, the numerical results are listed in the main FitlabGui window and when desired also in the logfile. In addition, plots of $\omega_n\sqrt{1-\zeta^2}$ versus $-\zeta\omega_n$ are provided in comparison to the corresponding HQ levels as in figure 7 or 23 of ADS-33 [2].

When used from a script with successive peaks as the method, the routine `findPeaks` is used to detect minima and maxima in the attitude signal. Depending on the number of peaks found, three or five peaks are used in equation 3.2 and the corresponding calculations. If model fit is chosen as the method, fixed starting values of $\zeta = 0.2$, $\omega_n = 0.3$, $t_0 = 0.1$ and $A = 5$ are used for optimizing equation 3.5. For the peak overshoot method, the starting time of the input and the peak value of the response are determined automatically and the steady-state value is determined from the last 20% of the time section.

## 3.6 Attitude Quickness

The attitude quickness criterion evaluates the response to aggressive control inputs with moderate amplitudes and thus yields the connection between the bandwidth and the large amplitude criteria. The criterion shows how fast the helicopter is able to transition from one stationary attitude to another stationary attitude without large pilot corrections.

The criterion assumes the response characteristics to be those of a 2nd order system. The parameters of the criterion are the attitude quickness, defined as the ratio of the maximum angular rate to the peak attitude change $p_{pk}/\Delta\phi_{pk}$ ($q_{pk}/\Delta\theta_{pk}$, $r_{pk}/\Delta\psi_{pk}$) and the minimum attitude change $\Delta\phi_{min}$ ($\Delta\theta_{min}$, $\Delta\psi_{min}$) during transition from one attitude to another.

Figure 3.6 shows the panel for the attitude quickness criterion. The selection of axis, speed, agility level, time sections and data channels is the same as for the dynamic stability criterion (see section 3.5). If the roll or yaw axis has been selected, the user

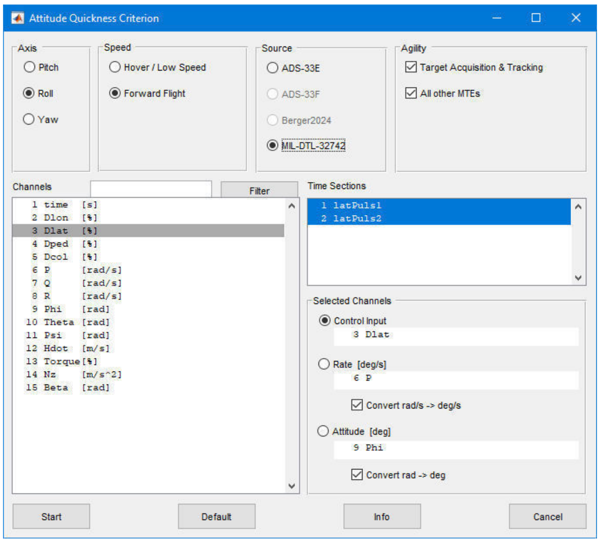


Figure 3.6: Attitude Quickness Criterion Panel

has the choice between using the boundaries from ADS-33E [2], ADS-33F [3], MIL-DTL-32742 [1], or the paper from Berger [9]. Pressing the **Start** button initiates a plot of control input, angular rate and attitude angle. Peak attitude change, minimum attitude change and peak angular rate have to be marked by the user in the corresponding diagrams.

Once all selected time sections have been handled, the numerical results are listed in the main FitlabGui window and optionally also in the logfile. The results for peak angular rate versus minimum attitude change are shown in comparison to the corresponding HQ levels in plots as in figures 8, 10 or 18 of ADS-33E [2], figure 8 of ADS-33F [3], figures 34, 37, 47 of MIL-DTL-32742 [1], or figure 45 from [9].

In script use without user interaction peak attitude change, minimum attitude change and peak angular rate are determined automatically.

## 3.7 Large Amplitude

This criterion addresses large-amplitude changes in attitude. The criterion measures the absolute control power in terms of the maximum achievable angular rate (for rate response types) or maximum achievable attitude change from trim (for attitude response types). For the yaw response in forward flight, the criterion parameter changes to the achievable heading change within one second following an abrupt pedal step input.

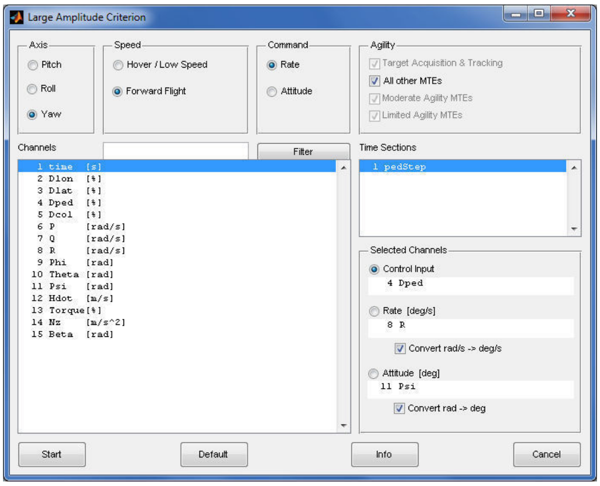


Figure 3.7: Large Amplitude Criterion Panel

The panel for the large amplitude criterion is shown in figure 3.7. The selection of axis, speed, time sections and data channels is the same as for the dynamic stability and attitude quickness criteria (see sections 3.5 and 3.6). An additional radio button is provided to switch between rate command and attitude command control systems. The available choices for the agility level(s) for which the plots are to be generated, depends on the choices for axis, speed, and control system type.

Pressing the **Start** button initiates a plot of control input, angular rate and attitude angle. The maximum angular rate resp. the maximum angular attitude change is determined automatically and marked in the plot.

For the yaw response in forward flight, the initial time of the step input has to be determined first. This can either be done automatically or manually by the user. Once the initial time has been determined, the heading change within one second is determined automatically.

After all selected time sections have been handled, the numerical results are listed in the main FitlabGui window and optionally in the logfile. In addition, plots are produced that show the maximum angular rate (resp. maximum attitude change or heading change in one second) versus the case number with the HQ level limits from tables VI or IX of ADS-33 [2] included.

In script use, the step is always detected automatically.

## 3.8 Spiral Stability

The spiral stability criterion allows helicopters to have a slightly unstable spiral mode in forward flight. Limits are given for the time to double of the bank angle amplitude following a lateral pulse control input.

A method for determining the time to double $T_2$ is given in [13]. The time response of the bank angle response has to be plotted on a semilog scale. The spiral component is then the time-averaged response after the first few seconds where the roll and Dutch roll modes still dominate the response. As long as there are no nonlinearities in the response, the spiral is well approximated by a straight line drawn through the time history after the initial response. The time to double is then determined as

$$T_2 = \ln 2 \, \frac{-(t_2 - t_1)}{\ln(\hat{\phi}_2/\hat{\phi}_1)} \tag{3.8}$$

where $\hat{\phi}_1$ and $\hat{\phi}_2$ are values of the linear approximation of the bank angle curve at times $t_1$ and $t_2$.

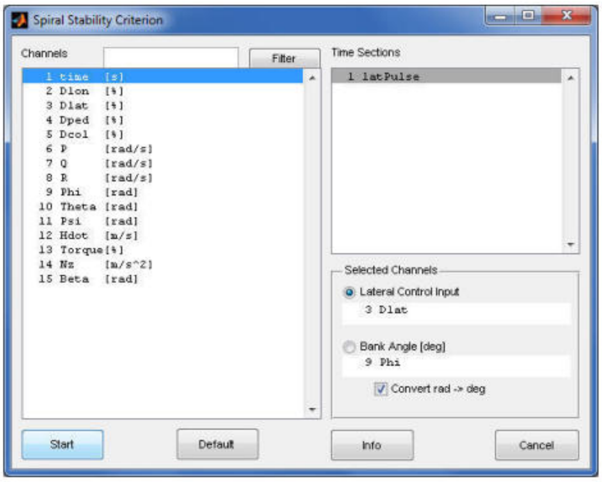


Figure 3.8: Spiral Stability Criterion Panel

Figure 3.8 shows the panel for the spiral stability criterion. The user has to select the time sections to be evaluated and the data channels for the lateral control input and the bank angle. After pressing the **Start** button, both signals are plotted and the user is asked if the response is unstable. For an unstable response, the bank angle is redrawn on a semilog scale and the user is asked to mark the start and end of the time interval for the approximation. A linear fit for the marked interval is then performed and the time to double determined according to equation 3.8. If the response is stable, the criterion just moves on to the next time section.

Once all time sections have been evaluated, the numerical results are listed in the FitlabGui window and optionally in the logfile and a plot appears that shows the time to double versus the case numbers and includes the HQ level limits from the ADS-33 [2].

In script use, the spiral is assumed to be unstable, if the maximum in $|\Delta\phi|$ occurs in the last 10% of the time section. For an unstable response, the second half of the free response is used as the time interval for the approximation.

## 3.9 Height Response

The height response criterion is aimed at measuring the dynamic behavior following collective inputs - in particular the vertical damping and equivalent vertical axis time delay. The ADS-33 requirement for the vertical response in hover is based on the premise that the altitude rate responds to collective inputs as a first order system for at least five seconds following a step collective input [2]. This first order system is defined by the transfer function

$$\frac{\dot{h}}{\delta_0} = \frac{K e^{-\tau_{\dot{h}eq} s}}{T_{\dot{h}_{eq}} s + 1} \tag{3.9}$$

where $K$ is the gain, $\tau_{\dot{h}_{eq}}$ is the equivalent time delay of the system (to account for actuation and rotor dynamics) and $T_{\dot{h}_{eq}}$ is the equivalent time constant. The handling qualities requirements are formulated in terms of the time constant and the time delay.

The ADS-33 [2] states that the equivalent system parameters shall be obtained by a time domain least squares fit of the function

$$\dot{h}_{est}(t) = K \left(1 - e^{-\frac{t-\tau_{\dot{h}eq}}{T_{\dot{h}eq}}}\right) \tag{3.10}$$

to the five seconds of vertical rate response following the collective step input. The coefficient of determination

$$r^2 = \frac{\sum_{i=1}^{n} \left(\dot{h}_{est}(t_i) - \dot{h}_{mean}\right)^2}{\sum_{i=1}^{n} \left(\dot{h}(t_i) - \dot{h}_{mean}\right)^2} \quad \text{with} \quad \dot{h}_{mean} = \frac{1}{n} \sum_{i=1}^{n} \dot{h}(t_i) \tag{3.11}$$

shall be in the range $0.97 < r^2 < 1.03$ for the fit to be valid. This method does not use the actual collective control input but assumes that a perfect step input was used.

Alternatively, a time domain fit using a simulation with the transfer function from equation 3.9 and the measured collective control input can be performed to obtain the criterion parameters $T_{\dot{h}_{eq}}$ and $\tau_{\dot{h}_{eq}}$. This method was developed at DLR [14] and uses the measured control input and thus can handle non-perfect step inputs (or any other input). The coefficient of determination is calculated in the same way as for the ADS-33 method.

Another alternative way for evaluating this criterion is a transfer function fit in the frequency domain as suggested by Ockier in [14]. This method needs frequency response data for altitude rate due to collective input $\dot{h}/\delta_0$ that is usually derived from a collective frequency sweep.

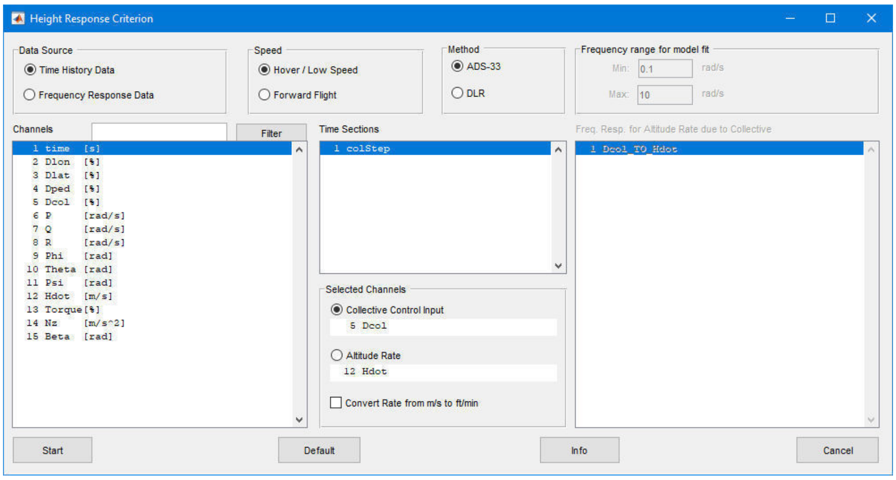


Figure 3.9: Height Response Criterion Panel

The panel for the height response criterion is shown in figure 3.9. On the top left, the user has to choose whether he wants to evaluate **Time History Data** or **Frequency Response Data** and whether the criterion is to be applied for **Hover / Low Speed** or **Forward Flight** data. Using the height response criterion for time domain data in forward flight corresponds to applying the flightpath response to pitch attitude criterion for backside operation (see section 3.10).

For time history data, the data channels for collective control input and altitude rate as well as the time sections to be evaluated have to be specified in the left part of the panel. Radio buttons allow to switch between the **ADS-33** and **DLR** method for the time domain fit. After pressing the **Start** button, a time history plot of control input and altitude rate appears and the user is asked whether the step initial time is to be detected automatically or manually. Once the step initial time has been detected, a window with starting values for the model parameters to be optimized appears. The optimization ist started by pressing the **Ok** button and the resulting match is plotted once the calculation is finished.

For the evaluation in the frequency domain, frequency response data for altitude rate due to collective control input has to be specified. The **Frequency Range** to be used for the model fit is specified in the upper right of the panel. The identification algorithm for estimating polynomial transfer function models in FitlabGui [7] is then used to fit a transfer function of the form from equation 3.9 to the measured frequency response. No starting values are required and the match resulting from the optimization is shown in a bode plot.

As defined in ADS-33 [2], the time delay $\tau_{\dot{h}_{eq}}$ can be negative. Due to the way the algorithms are implemented, the DLR and the frequency domain method do not allow for negative time delays.

Once all time sections or frequency responses have been evaluated, the numerical results are displayed in the main FitlabGui window and optionally written to the logfile. In addition, a plot of time delay versus the inverse of the time constant is shown with the corresponding HQ levels from table VII of ADS-33 [2] included.

In script use of the time domain variant, the step is detected automatically and fixed starting values are used for the optimization.

## 3.10 Flightpath Response to Pitch

The flightpath response to pitch attitude criterion as implemented in HQ-Tools pertains to the frontside of the power curve. For the purposes of this requirement, frontside operation is defined when the slope of the steady-state response of flight path angle vs. airspeed, $\Delta\gamma_{SS}/\Delta V_{SS}$, resulting from a step change in pitch attitude is negative. In this case, the criterion parameter is the lag between the vertical rate and the pitch attitude response. In the HQ-Tools implementation, the lag is determined in the frequency domain.

For backside operations, limits are defined for the model parameters when fitting the height response with the model from equation 3.9 in the preceding section. Thus backside operation is covered in the height response criterion (see section 3.9).

Figure 3.10 shows the flightpath response panel. The user has to select frequency responses for vertical rate and pitch attitude due to longitudinal control input. Both frequency responses need to have the same frequency axis. After pressing the **Start** button, the frequency response

$$\frac{\dot{h}}{\theta} = \frac{\dot{h}}{\delta_{lon}} / \frac{\theta}{\delta_{lon}} \tag{3.12}$$

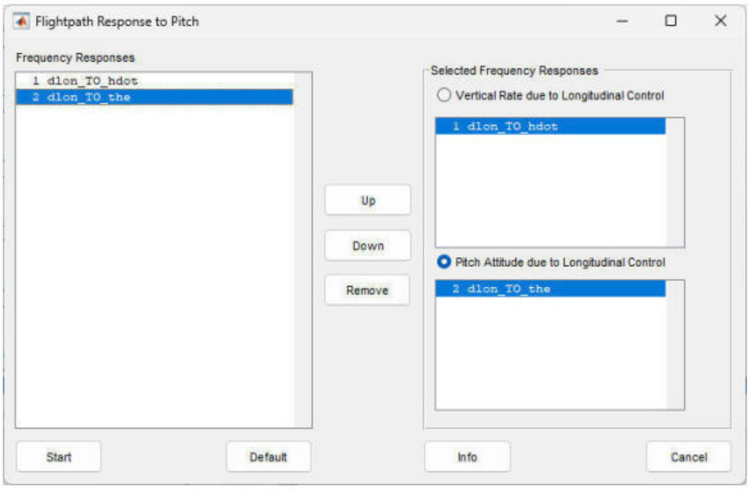


Figure 3.10: Flightpath Response Criterion Panel

is calculated and displayed in a bode plot. The frequency of the -45°-crossing is determined automatically and marked in the plot. The results are then plotted in comparison to the limits from ADS-33 [2].

## 3.11 Torque Response

The torque response criterion uses the torque displayed to the pilot as a measure of the maximum allowable power that can be commanded without exceeding engine or transmission limits. The criterion imposes limits on the time $t_p$ at which the peak of torque $Q_0$ occurs and the amount of torque overshoot $Q_0/Q_1$. Here, $Q_1$ is the first torque minimum occuring within ten seconds of the initiation of the collective step input. If no torque minimum is present within these ten seconds, $Q_1$ is taken as the torque at 10 seconds.

Figure 3.11 shows the torque response panel. The user has to select the time sections to be evaluated and specify the data channels for collective input and torque. After pressing the **Start** button, a time history plot appears and the step initial time has to be selected either automatically or manually. Next, the user is requested to mark the peak torque value and is asked whether a torque minimum occurs within ten seconds after the step initial time. If such a minimum occurs, the user is requested to mark it, otherwise, the torque at ten seconds is determined automatically.

Once all time sections have been processed, the numerical results are listed in the FitlabGui window and optionally in the logfile. In addition, a plot of overshoot ratio

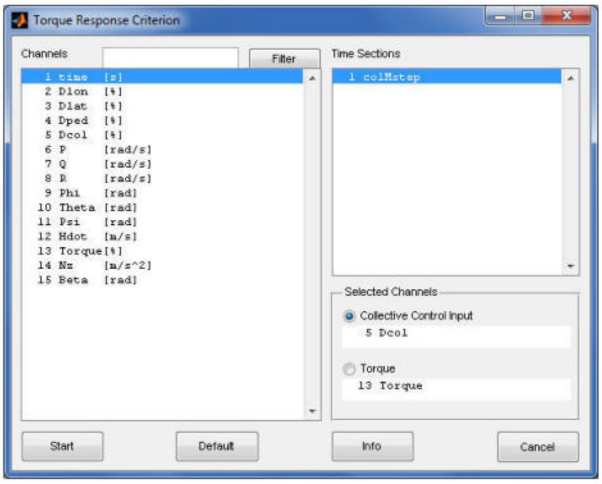


Figure 3.11: Torque Response Criterion Panel

versus time to first peak is drawn with the limits of the HQ levels included as in figure 14 of ADS-33 [2].

For script use without user interaction, the step initial time is always determined automatically. The routine `findPeaks` is used to find the peak and minimum torque values.

## 3.12 Pitch due to Collective

The pitch due to collective criterion in forward flight places limits on the pitch attitude change occurring within three seconds of an abrupt change in collective. The amount of pitch angle change is weighted against the amount of normal acceleration $n_z$ that is generated by the collective input. The criteria limits are expressed in terms of the peak pitch angle to peak normal acceleration ratio $|\theta_{pk}/n_{z_{pk}}|$ and are grouped by torque step size.

Figure 3.12 shows the pitch due to collective coupling panel. The user has to select the time sections to be evaluated and the data channels for collective control input, vertical acceleration, pitch attitude, and torque. After pressing the **Start** button, a time history plot is drawn and the step initial time selected automatically or manually. Once the step initial time has been determined, the peak normal acceleration and peak pitch attitude as well as the step size in torque are determined automatically and marked in the plot.

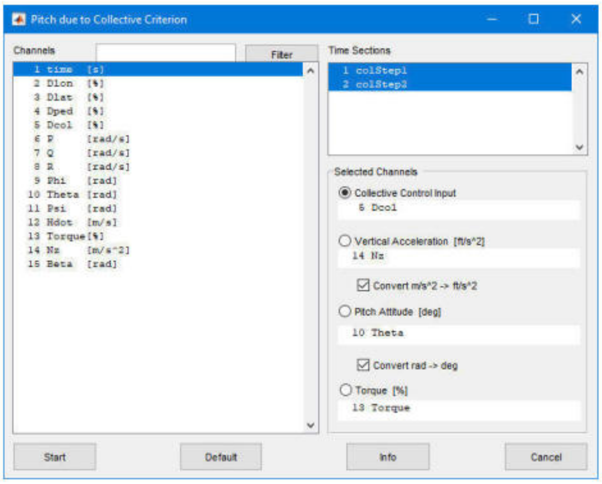


Figure 3.12: Pitch due to Collective Criterion Panel

After all time sections have been evaluated, the numerical results are listed in the main FitlabGui window and optionally in the logfile. Also, a plot of $|\theta_{pk}/n_{z_{pk}}|$ versus torque step size is drawn with the ADS-33 limits from section 3.4.5.1 included.

For script use, the step initial time is always detected automatically.

## 3.13 Yaw due to Collective

The yaw due to collective criterion limits the yaw rate response to abrupt collective inputs with the directional controller free. The criterion is specified in terms of two parameters, a mid-term response parameter $r_3/|\dot{h}(3)|$ and a short-term response parameter $|r_1/\dot{h}(3)|$.

$r_1$ is the peak yaw rate which occurs in the first three seconds after the collective input or, if there is no obvious peak yaw rate, the yaw rate one second after the collective input. $r_3$ is the yaw rate change between the first and the third second after the input (between $r(1)$ and $r(3)$). The sign of $r_3$ is positive if $r(1)$ and $r(3)$ have the same sign (i.e. the yaw rate change is continuous) and negative if $r(1)$ and $r(3)$ have different signs (i.e. the yaw rate change is oscillatory in nature). $\dot{h}(3)$ is the rate of climb or descent measured three seconds after the collective input.

Figure 3.13 shows the yaw due to collective coupling panel where the user has to specify the time sections to be evaluated and the data channels for collective control input, yaw rate, and altitude rate. After pressing the **Start** button, a time history plot

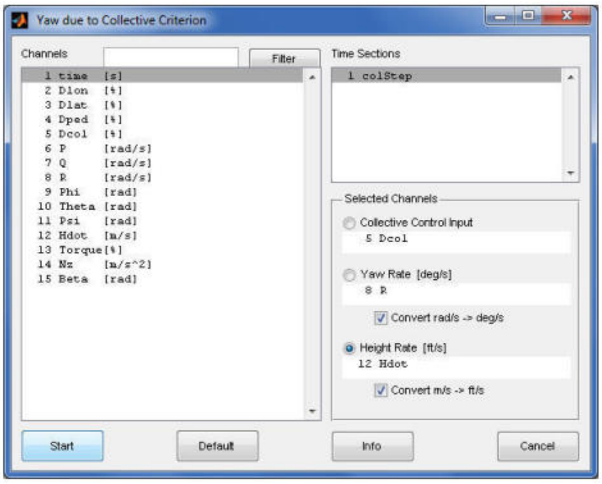


Figure 3.13: Yaw due to Collective Criterion Panel

appears and the step initial time has to be detected either automatically or manually by the user. Then, the user is asked whether the peak yaw rate occurs within three seconds of the step input. Depending on the answer, the peak yaw rate or the yaw rate after one second is determined automatically and the criterion parameters are calculated.

After all selected time sections have been evaluated, the numerical results are listed in the FitlabGui window and optionally also in the logfile. In addition, a plot of $|r_1/\dot{h}(3)|$ versus $r_3/|\dot{h}(3)|$ including the HQ level limits as in figure 11 of ADS-33 [2] is drawn.

For script use without user interaction, the step initial time is always determined automatically and the routine `findPeaks` is used to find the peak yaw rate in the response.

## 3.14 Pitch-Roll Coupling

The ADS-33 criteria for roll-to-pitch (i.e. pitch due to roll) and pitch-to-roll (i.e. roll due to pitch) coupling are defined in the time domain for aggressive agility and in the frequency domain for target acquisition and tracking.

The time domain requirements are defined in terms of the ratio of the peak off-axis attitude response to desired on-axis response, i.e. $\Delta\theta_{pk}/\Delta\phi_4$ for roll-to-pitch and $\Delta\phi_{pk}/\Delta\theta_4$ for pitch-to-roll coupling. The peak off-axis response must be measured within four seconds following an abrupt longitudinal or lateral cyclic step input; the desired on-axis response must be measured exactly four seconds after the input.

The frequency domain requirements are defined in terms of the average pitch-due-to-roll ($q/p$) and roll-due-to-pitch ($p/q$) that are derived from ratios of pitch and roll frequency responses. The average $q/p$ is defined as the magnitude of pitch-due-to-roll control input ($q/\delta_y$) divided by roll-due-to-roll control input ($p/\delta_y$) averaged between the bandwidth and neutral-stability (phase = -180°) frequencies of the pitch-due-to-pitch control inputs ($q/\delta_x$). Analogously, average $p/q$ is defined as the magnitude of $p/\delta_x$ divided by $q/\delta_x$ between the roll-axis $p/\delta_y$ bandwidth and neutral stability frequencies.

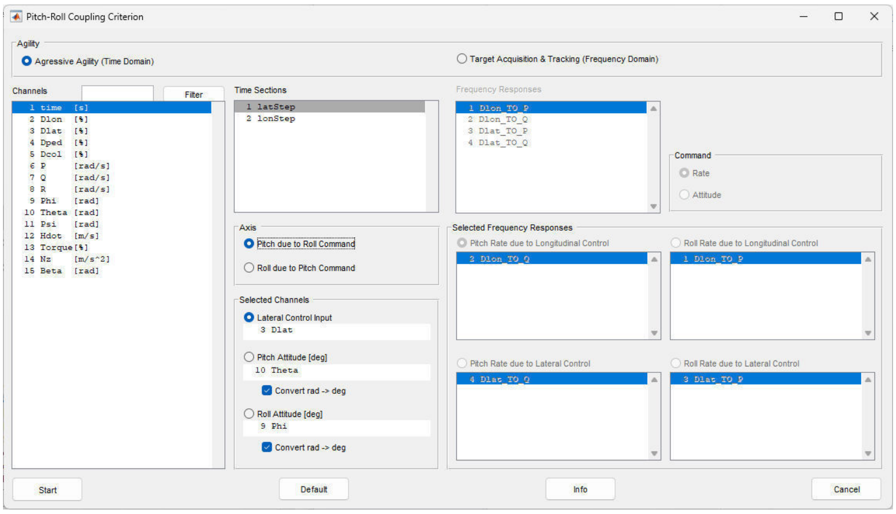


Figure 3.14: Pitch-Roll Coupling Criterion Panel

Figure 3.14 shows the panel for the pitch-roll coupling criterion. The left part of the panel pertains to the time domain criterion for aggressive agility whereas the frequency domain pitch-roll coupling criterion for target acquisition and tracking is invoked by the right part of the panel.

For the time domain criterion, the user has to specify the time sections to be evaluated and the data channels for lateral (longitudinal) cyclic control input and the pitch and roll attitude angles. After pressing the **Start** button, the initial time of the control input (step initial time or pulse peak time) has to be defined either automatically or manually. The peak off-axis response and the on-axis response after four seconds are calculated automatically. After all time sections have been processed, the numerical results are displayed in the main FitlabGui window and optionally in the logfile. In addition, the ratios of the peak off-axis attitude response to the desired on-axis response are plotted in comparison to the HQ level limits from section 3.3.9.2 from ADS-33 [2].

For the TAT cases that are evaluated in the frequency domain, the command type (rate or attitude) has to be chosen. Then, four frequency responses ($q/\delta_x$, $p/\delta_x$, $q/\delta_y$, $p/\delta_y$) have to be specified for each case.

Once the **Start** button is pressed, bode plots for the on-axis responses $\theta/\delta_x$ (integrated from $q/\delta_x$) and $\phi/\delta_y$ (integrated from $p/\delta_y$) appear, where the user has to select the correct 180°-crossing for the bandwidth calculation. After the bandwidth and neutral stability frequencies have been determined, the criterion parameters are calculated automatically. When all sets of frequency responses have been processed, a plot of the average $p/q$ versus the average $q/p$ as in figure 12 of ADS-33 [2] appears and the numerical results are listed in the FitlabGui window and optionally in the logfile.

For script use, the control input initial time for the time domain version as well as the -180°-crossing for the frequency domain version are determined automatically

## 3.15 Roll-Sideslip Coupling

The roll-sideslip coupling criterion places requirements on the amount of coupling that can exist between roll and sideslip for moderate bank angle change maneuvers such as turn entry. The way in which roll-sideslip coupling manifests itself is mainly a function of two parameters, the ratio of the amplitudes of the bank angle and sideslip angle envelopes of the Dutch roll mode, $|\phi/\beta|_d$, and the phase angle $\psi_\beta$ of the Dutch roll oscillation in sideslip following a lateral cyclic input.

The roll-sideslip criterion consists of two requirements: a limit on bank angle oscillations, and a limit on sideslip excursions during turn coordination. The bank angle oscillation limit is formulated through the ratio of the amount of Dutch roll oscillation versus the mean bank angle $\phi_{OSC}/\phi_{AV}$ This ratio is determined as

$$\frac{\phi_{OSC}}{\phi_{AV}} = \begin{cases} (\phi_1+\phi_3-2\phi_2)/(\phi_1+\phi_3+2\phi_2) & \zeta_d \leq 0.2 \\ (\phi_1-\phi_2)/(\phi_1+\phi_2) & \zeta_d > 0.2 \end{cases} \tag{3.13}$$

where $\phi_1$, $\phi_2$ and $\phi_3$ are the bank angles at the first, second and third peaks following an impulse lateral cyclic input and $\zeta_d$ is the damping ratio of the Dutch roll oscillation.

The phase angle $\psi_\beta$ is determined as

$$\psi_\beta = -360 t_{n\beta}/T_d + (n-1)360 \quad \text{with} \quad T_d = \frac{2\pi}{\omega_d\sqrt{1-\zeta_d^2}} \tag{3.14}$$

where $T_d$ and $\omega_d$ are the period and the natural frequency of the Dutch roll and $t_{n\beta}$ is the time to the $n$-the sideslip peak (minimum or maximum).

The limit on sideslip excursions uses the ratio of the maximum change in sideslip to the initial peak magnitude in roll response, $|\Delta\beta/\phi_1|$, as criteron parameter. Here $|\Delta\beta|$ is the maximum change in sideslip within the time $t_{\Delta\beta} = \min(6 \text{ sec.}, T_d/2)$. In addition, if the ratio of the amplitudes of the bank angle and sideslip amplitudes, $|\phi/\beta|_d$, exceeds 0.2, the product $5 \times |\Delta\beta/\phi_1| \times |\phi/\beta|_d$ is to be used as an additional criterion parameter (see [2]).

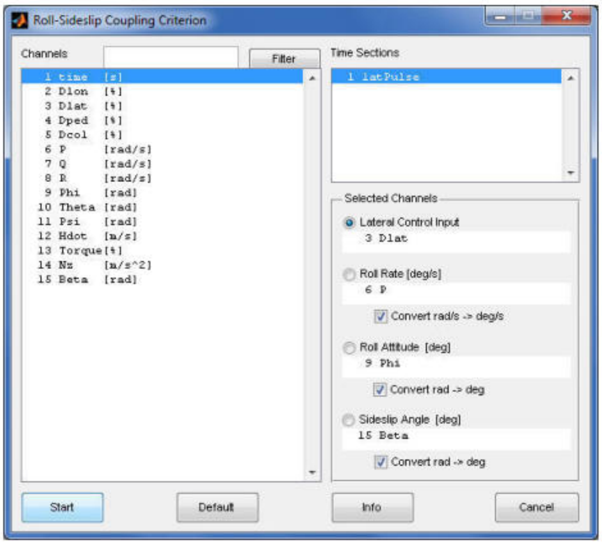


Figure 3.15: Roll-Sideslip Coupling Criterion Panel

Figure 3.15 shows the panel for the roll-sideslip coupling criterion where the user has to specify the time sections to be evaluated and the data channels for lateral control input, roll rate, roll attitude, and sideslip angle. After pressing the **Start** button in the roll-sideslip coupling panel, the user first has to mark three to five consecutive peaks in roll attitude that are then used to determine the Dutch roll frequency and damping. Depending on the resulting damping ratio, the ratio $\phi_{OSC}/\phi_{AV}$ is determined from the first two or three bank angle peaks according to equation 3.13.

Then $t_{\Delta\beta}$ is determined and the user has to mark the minimum and maximum sideslip values within this time interval to determine the maximum sideslip change $\Delta\beta$. Next, the user has to mark the first or second peak (minimum or maximum) in the sideslip time history to define $t_{n\beta}$ so that $\psi_\beta$ can be determined from equation 3.14 with $n = 1$ or $n = 2$. To determine the time by which the response in roll rate leads the sideslip response, the corresponding peak in roll rate has to be marked. The time difference of the peaks (minima or maxima) is then converted into a phase angle using the period of the dutch roll.

Finally, a new figure opens where the first two diagrams show bank angle and sideslip with envelopes of the free response approximated by splines. The third diagram shows the the ratio of the two envelope splines $\Phi/\beta$ and the user has to specify the time at which the ratio is to be taken for evaluation of the criterion.

Once all time sections have been evaluated, the numerical results are listed in the FitlabGui window and optionally in the logfile. In addition, plots of $\phi_{OSC}/\phi_{AV}$ versus $\psi_\beta$, $|\Delta\beta/\phi_1|$ versus $\psi_\beta$, and $5 \times |\Delta\beta/\phi_1| \times |\phi/\beta|_d$ versus $\psi_\beta$ are displayed with the HQ levels indicated as in figures 20 and 21 of ADS-33 [2].

In script use, the start time of the step input or the time of the peak of the pulse input is first determined automatically. The routine `findPeaks` is then used to find the peaks (minima and maxima) in the free response of roll angle, roll rate and sideslip. The maximum sideslip excursion is determined automatically from the sideslip values within the time $t_{\Delta\beta}$. Depending on the number of peaks found in sideslip, $n = 1$ or $n = 2$ is chosen and $t_{n\beta}$ as well as the corresponding peak in roll rate is determined automatically. Finally, the ratio of the envelopes of bank angle and sideslip is taken at the time of the second peak in $\phi$ to determine $|\phi/\beta|_d$.

## 3.16 Pitch Attitude Dropback

The pitch attitude dropback criterion is originally a fixed-wing criterion that has recently been applied to high-speed rotorcraft and modified boundaries have been suggested by Berger in [8]. The criterion evaluates the pitch attitude overshoot and dropback. These parameters are defined in figure 37 of MIL-STD-1797B [4]. The criterion requires time history data from a longitudinal pulse input (step and step back).

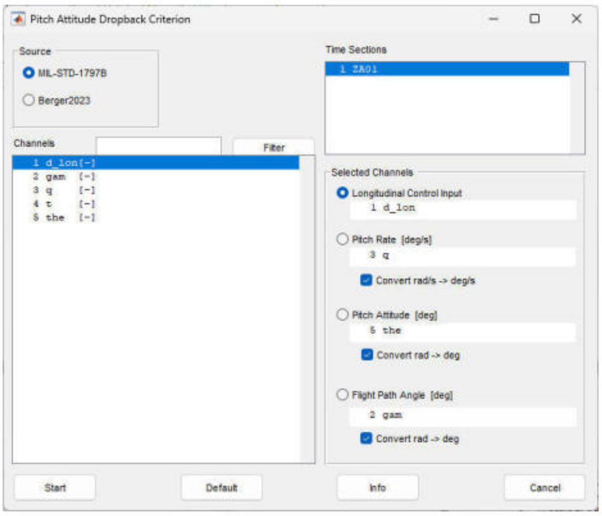


Figure 3.16: Pitch Attitude Dropback Criterion Panel

Figure 3.16 shows the panel for the pitch attitude dropback criterion. The user has to specify the time section(s) to be evaluated and the data channels for longitudinal control input, pitch rate, pitch attitude, and flightpath angle. In the upper left of the panel, the user can choose between the criterion boundaries from the MIL-STD-1797B [4] or suggested boundaries from Berger [8].

After pressing the **Start** button, the user has to choose between manually specifying the start and stop times of the step or automatic step detection. The peak and steady-state pitch rate, the pitch attitude dropback and dropback delay as well as the flightpath delay and incidence lag are then determined automatically.

Dropback divided by steady-state pitch rate is then plotted versus the ratio of peak and steady-state pitch rate against the level boundaries from MIL-STD-1797B [4] or the suggested boundaries from Berger [8].

In script use without user interaction, the step and step back is detected automatically.

## 3.17 Flightpath Bandwidth

The flightpath bandwidth criterion evaluates the relation of the flight path response to pitch attitude. The criterion requires frequency response data for pitch attitude to longitudinal control input and for flight path angle due to longitudinal control input.

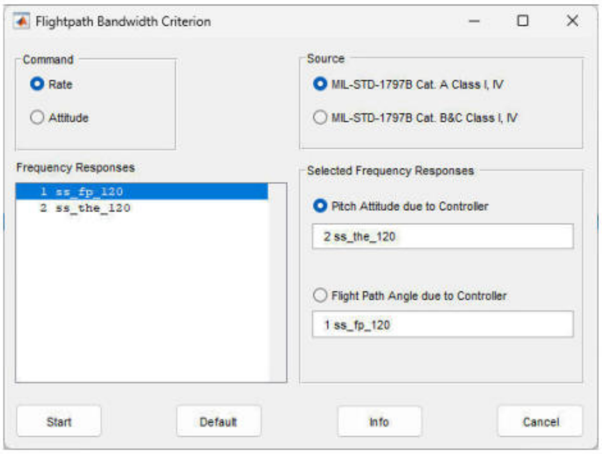


Figure 3.17: Flightpath Bandwidth Criterion Panel

Figure 3.16 shows the panel for the flightpath bandwidth criterion. In the upper part of the panel, the user has to specify whether a rate command or attitude command system is used and for which category of aircraft the limits are to be used. The necessary frequency responses have to be selected in the lower part of the panel.

After pressing the **Start** button, the user has to choose between manually or automatically determining the -180°-crossing. Bandwidth and time delay for each frequency response are the determined and the bandwidth ratio is then plotted against the limits from MIL-STD-1797B [4]. In script use without user interaction, the -180°-crossing is determined automatically.

## 3.18 Roll Performance

Roll performance is measured by the time to achieve a certain bank angle when full roll control is applied. The criterion thus requires time history data for maximum lateral control input. So far, this criterion is implemented only for category A aircraft where the bank angle to be achieved is 60° for class I and 45° for class II.

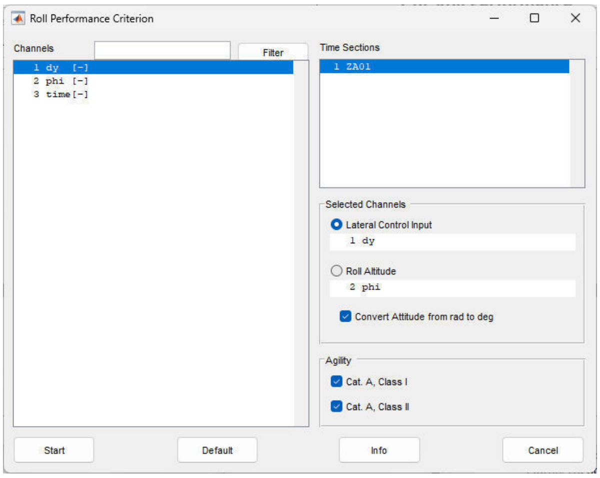


Figure 3.18: Roll Performance Criterion Panel

Figure 3.18 shows the panel for the roll performance criterion. The data channels for lateral control input and roll attitude (bank angle) have to be selected as well as the agility levels that shall be used.

After pressing the **Start** button, the user has to choose between manually or automatically determining the initial time of the control input. The time to achieve the desired bank angle is then determined automatically and plotted against the limits from MIL-STD-1797B [4].

# 4 Other Parameters

In addition to the HQ-parameters criteria that are defined in ADS-33 [2] or MIL-STD-1797B [4], HQ-Tools allows to calculate the

- RMS / Cutoff Frequency, and
- Attack Parameter

and to perform a Time Frequency Analysis.

## 4.1 RMS / Cutoff Frequency

The RMS (root mean square) value or quadratic mean is defined in the time domain as

$$RMS = \sqrt{\frac{1}{N}\sum_{n=1}^{N} x_n^2} \tag{4.1}$$

According to Parseval's theorem, this can alternatively be written in the frequency domain as

$$RMS = \sqrt{\frac{1}{N^2}\sum_{k=1}^{N} X_k^2} \tag{4.2}$$

when $X_k$ are the Fourier transform coefficients of $x$.

Let $\delta$ be a control input signal with a power spectral density (PSD) $G_{\delta\delta}$. If $\sigma_1$ denotes the RMS of this control input for the frequency range of $O$-$\omega_1$, and if the frequencies $\omega$ are in rad/s, then $\sigma_1$ is calculated from

$$\sigma_1^2 = \frac{1}{2\pi}\int_0^{\omega_1} G_{\delta\delta} d\omega \tag{4.3}$$

that is by integrating the power spectrum over the specified frequency range. Similarly, the total RMS $\sigma_{tot}$ is determined from

$$\sigma_{tot}^2 = \frac{1}{2\pi}\int_0^{\infty} G_{\delta\delta} d\omega \tag{4.4}$$

The pilot cutoff frequency $\omega_{CO}$ is defined as the half-power frequency. That means, $\omega_{CO}$ is the frequency $\omega_1$ such that

$$\left(\frac{\sigma_1}{\sigma_{tot}}\right)^2 = 0.5 \qquad \text{or} \qquad \frac{\sigma_1}{\sigma_{tot}} = \sqrt{0.5} = 0.70711 \tag{4.5}$$

In HQ-Tools, the power spectral density is determined using the method by Ockier (see Appendix A.4 of FitlabGui documentation [7]) and the integration is performed using the trapezoidal rule.

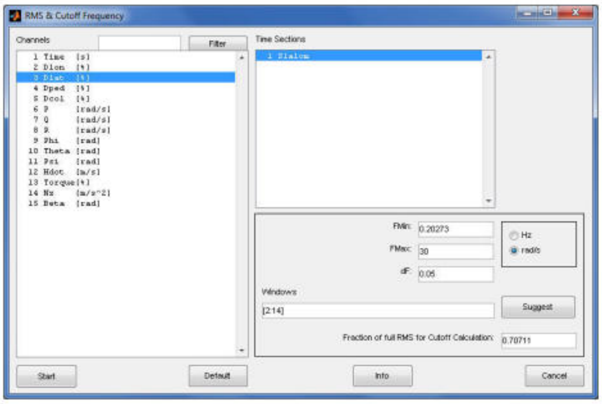


Figure 4.1: RMS/Cutoff Frequency Panel

Figure 4.1 shows the panel for the RMS / Cutoff Frequency calculation. On the left side, the user has to specify the signal for which the calculation is to be performed and on the top of the right side, the time sections for the calculation have to be selected. On the bottom of the right side, the frequency range and the desired frequency resolution have to be specified as well as the number of windows for the spectrum calculation. Pressing the **Suggest** button gives default values for these parameters. Last, the fraction of the full RMS, that is to be used for calculation of the cutoff frequency, has to be chosen. The default value for this fraction is $\sqrt{0.5}$.

After pressing the **Start** button, a plot appears for each selected time interval, that shows the power spectrum in the upper diagram. The bottom diagram contains the ratio of the partial RMS to the full range RMS with the cutoff frequency marked in the diagram.

Once all time sections have been processed, the calculated cutoff frequencies are listed in the FitlabGui window and optionally in the logfile.

## 4.2 Attack Parameter

The control attack parameter as introduced in [15] measures the size and rapidity of pilot control inputs. It is defined as

$$P_{attack} = \frac{\dot{\eta}_{pk}}{\Delta\eta} \tag{4.6}$$

where $\eta$ is the pilot control deflection. This means that $P_{attack}$ is the ratio of the peak control input rate $\dot{\eta}_{pk}$ to the difference $\Delta\eta$ of the control inputs at the beginning and the end of the regarded time interval.

For the calculation of the attack parameter, the control input signal has first to be filtered to remove noise and to allow determining the control input rate $\dot{\eta}$ by numerical differentiation. Next, the control reversals, i.e. the time points where the input rate changes sign, have to be located. Then each interval between two control reversals corresponds to one attack point and yields one value for $P_{attack}$. Intervals with control input changes $\Delta\eta$ below a certain lower threshold (usually 0.5%) are neglected.

In addition to the attack parameters itself, the following other parameters are also of interest:

1. Attack number: The total number of times that the pilot moves the control by more than the lower threshold.
2. Attack number per second: The attack number expressed in terms of the average number of control movements per second.
3. Mean attack rate: The mean rate at which the pilot is moving his control.
4. Mean control displacement: The mean of the control displacements measured for each of the attack points.

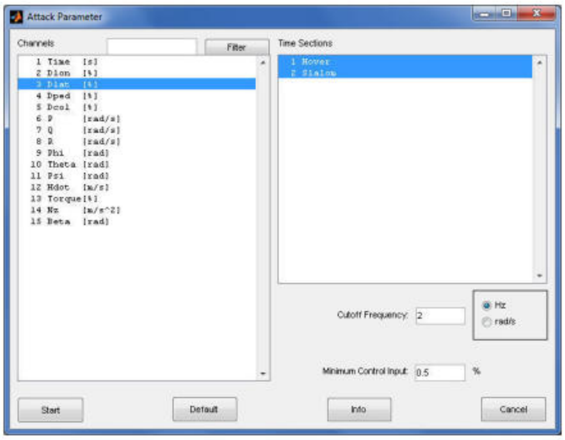


Figure 4.2: Attack Parameter Panel

Figure 4.2 shows the panel for the calculation of the attack parameter. On the left side, the control input to be evaluated has to be specified and on the top right, the time sections to be investigated have to be selected. Below the time section selection, the cutoff frequency for filtering the measured control input has to be specified. At the very bottom, the minimum control deflection to be considered has to be specified.

After pressing the **Start** button, a plot appears for each selected time interval, that shows the original und the filtered control input in the upper diagram. In the lower diagram, the control input rate is plotted and the identified rate reversals and peak rates are marked.

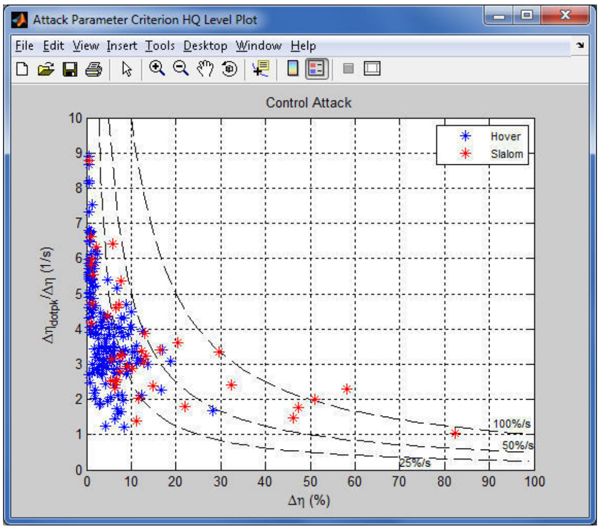


Figure 4.3: Attack Parameter Plot

Once all time sections have been processed, a plot like in figure 4.3 appears, that shows the attack parameter $P_{attack}$ versus the corresponding control change $\Delta\eta$ for all attack points. In the main FitlabGui window and optionally in the logfile, the attack number, attack number per second, mean attack rate and mean control displacement are listed for all time sections.

## 4.3 Time Frequency Analysis

The Time Frequency Analysis is used to characterize pilot control activity and especially the temporal variation in pilot control strategy. An overview over different time frequency representations and their analysis is given in refs. [16, 17]. Out of the methods presented in these papers, the spectrogram and the time-varying cutoff frequency and power frequency are implemented in HQ-Tools.

The spectrogram is the squared modulus of the Short-Time Fourier Transform (STFT), where the STFT is a Fourier transform (calculated by Chirp-z transform) in which the original signal is convolved with a sliding Hamming window of user specified length.

The time-varying cutoff frequency $\omega_{CO}(t_i)$ is similar in concept to the classical cutoff frequency (see section 4.1), but is computed from a time frequency representation $G_{\delta\delta}(\omega, t_i)$ (in this case the spectrogram) instead of the power spectral density. The time-varying power frequency $\omega_{pow}(t_i)$ is the time varying cutoff frequency scaled by the the maximum signal power at that time.

$$\omega_{pow}(t_i) = \omega_{CO}(t_i) \max_{\omega} G_{\delta\delta}(\omega, t_i) \tag{4.7}$$

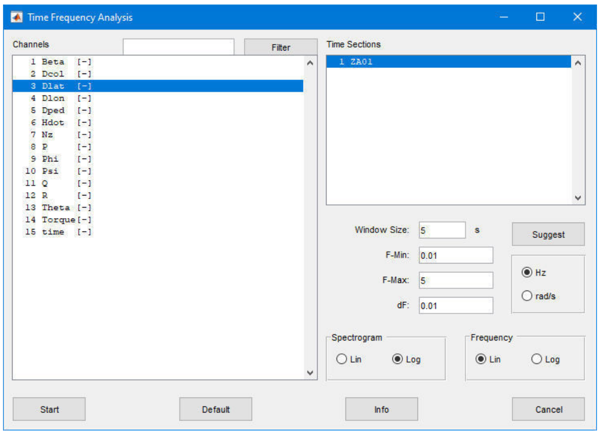


Figure 4.4: Time Frequency Analysis Panel

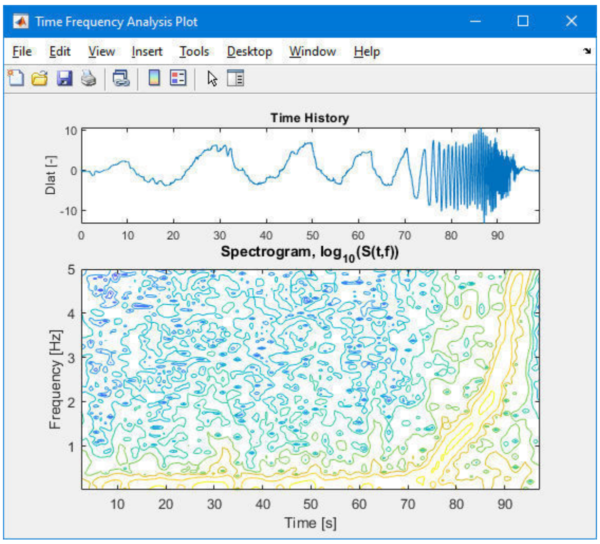


Figure 4.5: Example for a Spectrogram Contour Plot

Figure 4.4 shows the panel for the time frequency analysis. On the left side, the control input to be evaluated has to be specified and on the top right, the time section to be investigated has to be selected. Below the time section selection, the length of the sliding window has to be specified. The maximum length of this window must be less than 1/5 of the time section length. In addition, the frequency range of interest and the frequency resolution have to be given. Default values can be created by pressing the **Suggest** button. Radio buttons allow to switch between linear and logarithmic scaling for the display of the resulting spectrogram and for the frequency axes.

After pressing the **Start** button, three plot windows appear. The first window shows the control input in the top diagram and a contour plot of the spectrogram in the second diagram (see fig. 4.5 for an example). The second window contains the spectrogram as a 3-dimensional plot. The third window gives the control input in the top diagram and the time varying cutoff and power frequencies in two diagrams below it.

# 5 Mission Task Elements

For performing Mission Task Element maneuvers with the ACT/FHS both in the simulator and in flight tests, several MTE displays have been defined (see chapter 6 of [18]). All signals that are used in these displays are recorded in the CDF-datasets and thus are available for evaluating the MTE tests.

HQ-Tools allows to produce standardized plots from ACT/FHS data for the following Mission Task Elements:

- Hover
- Vertical Maneuver
- Lateral Reposition
- Depart / Abort
- Hovering Turn
- Slalom
- Pirouette
- Load Placement

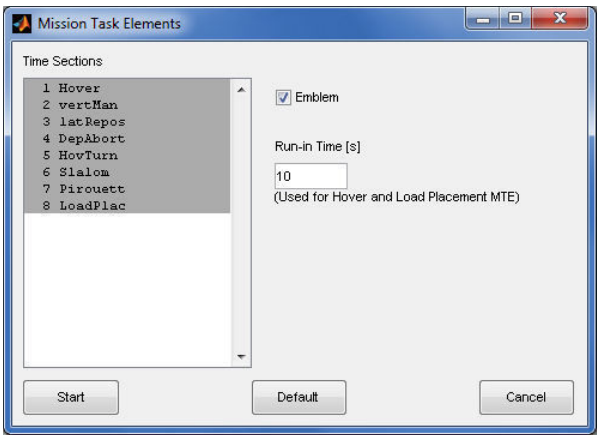


Figure 5.1: MTE Panel

Figure 5.1 shows the panel for the MTE plots. Out of all currently active time sections (marked with **on** in the panel from figure 2.1), the user has to select those for which he wants a MTE plot. The only options in the MTE panel are the checkbox for the emblem

Table 5.1: **MTEs coding in MTE_CDUDSP**

| MTE_CDUDSP | corresponding MTE |
|---|---|
| 0 | Hover |
| 1 | Vertical Maneuver |
| 2 | Lateral Reposition |
| 3 | Depart/Abort |
| 4 | Hovering Turn |
| 5 | Slalom |
| 6 | Pirouette |
| 7 | Acceleration/Deceleration |
| 8 | Sidestep |
| 9 | Landing |
| 10 | Load Placement |

Table 5.2: **Coding of rotorcraft category and visual environment (VE) in MTE_CDUPFS**

| | good VE | degraded VE |
|---|---|---|
| Scout/Attack | 0 | 1 |
| Cargo/Utility | 2 | 3 |
| Slung Load | 4 | 5 |
| User defined | 6 | 7 |

(DLR logo) and an optional run-in time for the hover and load placement MTEs. The active MTE for each time section is automatically read from the channel MTE_CDUDSP according to table 5.1. The rotorcraft category and visual environment are derived from MTE_CDUPFS according to table 5.2.

After pressing the **Start** button in the MTE panel, the corresponding MTE-Plot is created for each of the selected time sections. The data channels that are needed for each plot are listed in table 5.3. Due to their use in the MTE displays, many of the MTE signals are not recorded in physical units but as normalized values. For these signals, instead of the unit, the range corresponding to the interval [-1,1] is given. For example for the longitudinal and lateral control inputs, the range [-1,1] corresponds to [0%,100%] control input.

| MTE | Channel | Unit/Range | Description |
|---|---|---|---|
| all | MTE_CDUSTA | - | MTE CDU commanded mission state |
| | MTE_CDUDSP | - | MTE CDU display selection |
| | MTE_CDUPFS | - | MTE CDU performance set number |
| | I_CTL4AX_0 | % | collective control input |
| | I_CTL4AX_P | % | pedal control input |
| Hover | MTE_HVDSTA | - | Hover Display State<br>(0=init, 1,2=phase1/2, 3=evaluation) |

| MTE | Channel | Unit/Range | Description |
|---|---|---|---|
| | MTE_HVPIT | [0%,100%] | MTE Hov - Evaluation Pilot Pitch |
| | MTE_HVROL | [0%,100%] | MTE Hov - Evaluation Pilot Roll |
| | MTE_HVX | [-10ft,10ft] | MTE Hov - Relative Position X |
| | MTE_HVY | [-10ft,10ft] | MTE Hov - Relative Position Y |
| | MTE_HVHDG | deg | MTE Hov - Relative Heading |
| | MTE_HVALT | [-10ft,10ft] | MTE Hov - Relative Altitude |
| | MTE_HVSPD | m/s | MTE Hov - Ground Speed |
| | MTE_HVT1 | s | MTE Hov - Phase 1 Time |
| | MTE_HVT2 | s | MTE Hov - Phase 2 Time |
| Vert. Maneuver | MTE_VMDSTA | - | Vertical Maneuver Display State (0=init, 1=phase1, 2=evaluation) |
| | MTE_VMPIT | [0%,100%] | MTE Ver - Evaluation Pilot Pitch |
| | MTE_VMROL | [0%,100%] | MTE Ver - Evaluation Pilot Roll |
| | MTE_VMX | [-22ft,22ft] | MTE Ver - Relative Position X |
| | MTE_VMY | [-22ft,22ft] | MTE Ver - Relative Position Y |
| | MTE_VMHDG | rad | MTE Ver - Relative Heading |
| | MTE_VMALT | [-10ft,35ft] | MTE Ver - Relative Altitude |
| Lat. Reposition | MTE_LRDSTA | - | Lateral Reposition Display State (0=init, 1=phase1, 2=evaluation) |
| | MTE_LRPIT | [0%,100%] | MTE Lat - Evaluation Pilot Pitch |
| | MTE_LRROL | [0%,100%] | MTE Lat - Evaluation Pilot Roll |
| | MTE_LRX | [-450ft,450ft] | MTE Lat - Relative Position X |
| | MTE_LRY | [-25ft,25ft] | MTE Lat - Relative Position Y |
| | MTE_LRSPD | m/s | MTE Lat - Ground Speed |
| | MTE_LRHDG | rad | MTE Lat - Relative Heading |
| | MTE_LRALT | [-20ft,20ft] | MTE Lat - Relative Altitude |
| Depart/Abort | MTE_DPDSTA | - | Depart/Abort Display State (0=init, 1=phase1, 2=evaluation) |
| | MTE_DPPIT | [0%,100%] | MTE Dep - Evaluation Pilot Pitch |
| | MTE_DPROL | [0%,100%] | MTE Dep - Evaluation Pilot Roll |
| | MTE_DPX | [-900ft,100ft] | MTE Dep - Relative Position X |
| | MTE_DPY | [-25ft,25ft] | MTE Dep - Relative Position Y |
| | MTE_DPSPD | m/s | MTE Dep - Ground Speed |
| | MTE_DPHDG | rad | MTE Dep - Relative Heading |
| | MTE_DPRAD | [0ft,100ft] | MTE Dep - Radar Height |
| Hovering Turn | MTE_HTDSTA | - | Hovering Turn Display State (0=init, 1=phase 1, 2=evaluation) |
| | MTE_HTPIT | [0%,100%] | MTE Hvt - Evaluation Pilot Pitch |
| | MTE_HTROL | [0%,100%] | MTE Hvt - Evaluation Pilot Roll |
| | MTE_HTX | [-18ft,18ft] | MTE Hvt - Relative Position X |
| | MTE_HTY | [-18ft,18ft] | MTE Hvt - Relative Position Y |
| | MTE_HTALT | m | MTE Hvt - Relative Altitude |

| MTE | Channel | Unit/Range | Description |
|---|---|---|---|
| | MTE_HTHDG | rad | MTE Hvt - Relative Heading |
| Slalom | MTE_SLPIT | [0%,100%] | MTE Sla - Evaluation Pilot Pitch |
| | MTE_SLROL | [0%,100%] | MTE Sla - Evaluation Pilot Roll |
| | MTE_SLX | [-250ft,2750ft] | MTE Sla - Relative Position X |
| | MTE_SLY | [-150ft,150ft] | MTE Sla - Relative Position Y |
| | IN117_PHI | rad | INU Blended Roll Angle |
| | MTE_SLSPD | [0kt,80kt] | MTE Sla - Ground Speed |
| | MTE_SLRAD | [0ft,150ft] | MTE Sla - Normed Radar Height |
| Pirouette | MTE_PIDSTA | - | Pirouette Display State (0=init, 1,2,3=phase1/2/3, 4=evaluation) |
| | MTE_PIPIT | [0%,100%] | MTE Pir - Evaluation Pilot Pitch |
| | MTE_PIROL | [0%,100%] | MTE Pir - Evaluation Pilot Roll |
| | MTE_PIX | [-130ft,130ft] | MTE Pir - Relative Position X |
| | MTE_PIY | [-130ft,130ft] | MTE Pir - Relative Position Y |
| | MTE_PIALT | m | MTE Pir - Relative Altitude |
| | MTE_PIBEA | rad | MTE Pir - Relative Bearing |
| | MTE_PIRAD | m | MTE Pir - Relative Radius |
| | MTE_PIT1 | s | MTE Pir - Phase 1 Time |
| | MTE_PIT2 | s | MTE Pir - Phase 2 Time |
| | MTE_PIT3 | s | MTE Pir - Phase 3 Time |
| Load Placement | MTE_LPDSTA | - | Load Placement Display State (0=init, 1,2=phase1/2, 3=evaluation) |
| | MTE_LPPIT | [0%,100%] | MTE Lpl - Evaluation Pilot Pitch |
| | MTE_LPROL | [0%,100%] | MTE Lpl - Evaluation Pilot Roll |
| | MTE_LPLX | [-10ft,10ft] | MTE Lpl - Relative Load Position X |
| | MTE_LPLY | [-10ft,10ft] | MTE Lpl - Relative Load Position Y |
| | MTE_LPHSP | m/s | MTE Lpl - Helicopter Ground Speed |
| | MTE_LPLSP | m/s | MTE Lpl - Load Ground Speed |
| | MTE_LPHAL | [-10ft,10ft] | MTE Lpl - Relative Helicopter Altitude |
| | MTE_LPLAL | m | MTE Lpl - Load Altitude |
| | MTE_LPT1 | s | MTE Lpl - Phase 1 Time |
| | MTE_LPT2 | s | MTE Lpl - Phase 2 Time |

Table 5.3: **Necessary data channels for the different MTE plots**

# 6 Summary

HQ-Tools is an add-on to the software FitlabGui that allows for handling qualities analysis from simulated or flight test data. HQ-Tools encompasses eighteen quantitative HQ criteria and several additional HQ parameters and also provides specialized analysis plots for eight MTEs.

The quantative criteria allow to evaluate several time sections or several frequency responses together. The quantitative results are displayed in comparison to the HQ levels as defined in the MIL-DTL-32472 [1], ADS-33 [2], or MIL-STD-1797B [4].

The two additional HQ parameters, namely cutoff frequency and attack parameter, are determined from time domain data but have no HQ levels associated with them.

The MTE plots are specific to data from the ACT/FHS or the ground based simulator as they require special data channels. The user has to just specify the time sections to be evaluated and the program then automatically provides the plots for the corresponding MTEs.

This user’s guide describes how HQ-Tools is integrated into FitlabGui and what types of data are required are required for each criterion. All quantative criteria and HQ parameters are explained in detail as well as the use of the MTE plots.

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