ADMIRE The Aero-Data Model In a Research Environment Version 4.0, Model Description

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FOI-R--1624--SE User report **Systems Technology**
ISSN-1650-1942 December 2005

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Issuing organisation FOI – Swedish Defence Research Agency Systems Technology SE-164 90 STOCKHOLM	**Report number, ISRN** FOI-R--1624--SE	**Report type** User report
	Research area code Vehicles	
	Month year December 2005	**Project no.** E6118, I60131
	Sub area code Air Vehicles	
	Sub area code 2	
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	Sponsoring agency FMV	
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Report title
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Abstract
This document describes the nonlinear aircraft simulation model ADMIRE. It describes the main aircraft model, the flight control system, actuators, the sensor models and the uncertainty parameters with respective limits. This document also contains a description on how to properly install and run the model. The ADMIRE describes a generic small single seated, single engine fighter aircraft with a delta-canard configuration, implemented in MATLAB/SIMULINK Release 13. The model envelope is up to Mach 1.2 and 6000 m altitude. The model is augmented with a longitudinal flight control system (FCS) that controls the pitch rate at low speed and the load factor at higher speeds, and a lateral controller that controls the wind vector roll rate and the angle of sideslip. The longitudinal FCS also contains a very rudimentary speed controller. The model has thrust vectoring capability, although this is not used in the present FCS. For the purpose of the robustness analysis, the model is extended with the possibility to change some predefined uncertainty parameters within prescribed limits. The uncertainty parameters consist of configuration parameter-, aerodynamic-, actuator- and sensor (air data)-uncertainties. The model can be trimmed and linearized within the entire model envelope.

Keywords
ADMIRE, Flight control system, Aircraft model, Aircraft simulation, Robustness analysis

Further bibliographic information	**Language** English
ISSN ISSN-1650-1942	**Pages** 36 p.
	Price acc. to pricelist

Utgivare FOI – Totalförsvarets forskningsinstitut Systemteknik 164 90 STOCKHOLM	**Rapportnummer, ISRN** FOI-R--1624--SE	**Klassificering** Användarrapport
	Forskningsområde Farkoster	
	Månad år December 2005	**Projektnummer** E6118, I60131
	Delområde Luftfarkoster	
	Delområde 2	
Författare/redaktör Lars Forssell, Ulrik Nilsson	**Projektledare** Lars Forssell	
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	Uppdragsgivare/kundbeteckning FMV	
	Tekniskt och/eller vetenskapligt ansvarig Markus Högberg	

Rapportens titel
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Sammanfattning
Denna rapport beskriver den ickelinjära flygplanssimuleringsmodellen ADMIRE. Beskrivningen omfattar flygplanet, styrsystemet, aktuatorer, sensorer samt osäkerhetsparametrar. Beskrivningen omfattar även en instruktion om hur man installerar och kör modellen. Modellen ADMIRE beskriver ett litet ensitsigt enmotorigt jaktplan med en delta-canardkonfiguration. ADMIRE är implementerad i MATLAB/SIMULINK. Flygplanets envelop är upp till Mach 1.2, höjden 6000 m samt anfallsvinkel upp till 90°. Modellen har både ett longitudinell och ett lateralt styrsystem samt enveloppsbegränsningar. I modellen finns även dragkraftsvektorisering modellerat men används inte i den nuvarande utgåvan av styrsystemet. I syfte att möjliggöra robusthetsanalys har modellen försetts med ett antal osäkerhetsparametrar med tillhörande gränser. ADMIRE kan trimmas och linjäriseras i hela enveloppen.

Nyckelord
ADMIRE, Styrsystem, Flygplansmodell, Flygplanssimulering, Robusthetsanalys

Övriga bibliografiska uppgifter	**Språk** Engelska
ISSN ISSN-1650-1942	**Antal sidor:** 36 s.
Distribution **enligt missiv**	**Pris:** **Enligt prislista**

Contents

List of Abbreviations

ADMIRE	Aero-Data Model In Research Environment
AoA	Angle of Attack
ARI	Aileron-Rudder Interconnect
CAS	Control Augmentation System
c.g.	Centre of Gravity
CS	Control Selector
FCS	Flight Control System
FFA	Aeronautical Research Institute of Sweden
FOI	Swedish Defence Research Agency
Fortran	Formula Translation (Programming language)
FOSIM	Forskningssimulator (Research Simulator) at FFA
GAM	The Generic Aerodata Model
GARTEUR	Group for Aeronautical Research and Technology in EURrope
PC	Personal Computer
PPM	Pole Placement Method

List of Symbols

a	speed of sound (m/s)
b_{ref}	Wingspan (m)
c_{ref}	Mean aerodynamic chord (m)
C_l	Coefficient of rolling moment
$C_{l\beta}$	Rolling moment coefficient derivative with respect to β
C_m	Coefficient of pitching moment
$C_{m\alpha}$	Pitching moment coefficient derivative with respect to α
C_{m_q}	Pitching moment coefficient derivative with respect to q
C_n	Coefficient of yawing moment
C_{n_β}	Yawing moment coefficient derivative with respect to β
C_{n_r}	Yawing moment coefficient derivative with respect to r
C_D	Coefficient of drag
C_L	Coefficient of lift
C_X	Coefficient of axial force
C_Y	Coefficient of side force
C_Z	Coefficient of normal force
F_{as}	Force aileron stick
F_{es}	Force elevator stick
F_{rp}	Force rudder pedal
$F_{X_{\mathrm{aero}}}$	Total aerodynamic force in body-fixed x-axis
$F_{Y_{\mathrm{aero}}}$	Total aerodynamic force in body-fixed y-axis
$F_{Z_{\mathrm{aero}}}$	Total aerodynamic force in body-fixed z-axis
g	Acceleration due to gravity (m/s^2)
h	Altitude (feet or m)
I_x	x body moment of inertia (kg·m^2)
I_{xy}	x-y body axis product of inertia (kg·m^2)
I_{xz}	x-z body axis product of inertia (kg·m^2)
I_y	y body axis moment of inertia (kg·m^2)
I_{yz}	y-z body axis product of inertia (kg·m^2)
I_z	z-body moment of inertia (kg·m^2)
m	Aircraft total mass (kg)
M	Mach number
n_x, n_y, n_z	Load factor along x-, y- and z-axes respectively (g)
p_b	Body-fixed roll rate (deg/s)
p_{dem}	Demanded roll rate (deg/s)
q_b	Body-fixed pitch rate (deg/s)
q_{dem}	Demanded pitch rate (deg/s)
r_b	Body-fixed yaw rate (deg/s)
S_{ref}	Wing surface (m^2)
t	Time (s)
T_{ss}	throttle stick setting
`u0fcs(1)`	trim value of pitch stick force
`u0fcs(2)`	commanded speed
`u0fcs(3)`	trim value of roll stick force (usually zero)

`u0fcs(4)`	trim value of pedal force (usually zero)
u_b, v_b, w_b	Body-fixed velocities along x-, y- and z-axes respectively
u_p,u_q,u_β	Control channel roll, pitch and yaw
V_T	Total velocity (m/s)
x, y, z	Earth axes positions (m)
x_{cg}, y_{cg}, z_{cg}	Center of gravity location along x-, y- and z-axes respectively
x_v, y_v, z_v	Positions in vehicle carried reference frame (m)

List of Greek Symbols

α	Angle of attack (deg)
β	Angle of sideslip (deg)
γ	Flight path angle (deg)
δ	Vector of system parameters
δ_{lc}	Left canard deflection (deg)
δ_{ldg}	Landing gear deflection
δ_{le}	Leading edge flap deflection (deg)
δ_{lie}	Left inner elevon deflection (deg)
δ_{loe}	Left outer elevon deflection (deg)
δ_r	Rudder deflection (deg)
δ_{rc}	Right canard deflection (deg)
δ_{rie}	Right inner elevon deflection (deg)
δ_{roe}	Right outer elevon deflection (deg)
δ_{th}	Horizontal thrust vectoring
δ_{tv}	Vertical thrust vectoring
ϕ	Bank angle (deg)
θ	Pitch angle (deg)
ρ	Density of air (kg/m^3)
ψ	Heading angle (deg)
$\dot{(.)}$	Derivative with respect to time

List of Subscripts

err	Sensor measurement error (e.g. $\delta_{\mathrm{alt}_{\mathrm{err}}}$ is the measurement error on altitude)
sensor	Output sensor measurement value (e.g. ψ_{sensor} is the sensed value of ψ)
sl	Straight Level Flight condition
trim	Trim value of a variable (e.g. α_{trim} is the trimmed value of α)
unc	Uncertainty parameter (e.g. $C_{l\beta\mathrm{unc}}$ is the uncertainty parameter representing variation in $C_{l\beta}$)

1 Introduction

This document describes the build-up and the use of the ADMIRE within the project GARTEUR Flight Clearance FM(AG11). The main description of the ADMIRE and the modeled parametric uncertainties are described in Chapter 2. In Chapter 3, the Flight Control System (FCS) is described. The implementation in MATLAB/SIMULINK R13 can be found in Chapter 4.

Thanks to the people that all have contributed in a positive way to the development of the model: Hans Backström (Saab), David Bennet (BAe Systems), Binh Dang-Vu (ONERA), Holger Duda (DLR), Gunnar Duus (DLR), Chris Fielding (BAe Systems), Georg Hofinger (EADS), Gunnar Hovmark (FOI), Åke Hydén (FOI), Fredrik Johansson (FOI), Mangesh Kale (University of Southampton), Harrald Luijerink (TU Delft), Torbjörn Norén (FOI), Martin Näsman (FMV), Lars Rundqwist (Saab), Anton Vooren (Royal Norwegian Air Force), David Alan Weaver (FOI), and probably some more that we have forgotten to mention here.

2 Description of ADMIRE

In 1997 development of the model ADMIRE was started at FFA. The goal was to use the Generic Aerodata Model (GAM), developed by Saab AB, as a basis and construct a complete aircraft model for use in the research simulator FOSIM. A secondary goal was to provide the research community with an unlimited model that could freely be distributed. In order to get a complete model of a small fighter aircraft, the Generic Aerodata Model had to be completed with models of the engine, actuators, dynamics etc.

The ADMIRE is a generic model of a small single-seat fighter aircraft with a delta-canard configuration. The ADMIRE contains twelve states (V_T, α, β, p_b,q_b, r_b, ϕ, θ, ψ, x_v, y_v, z_v) plus additional states due to the presence of actuators, sensors and Flight Control System (FCS). Available control effectors are left and right canard, leading edge flaps, four elevons, rudder and throttle setting. The model is also equipped with thrust vectoring capability, air brakes and a choice to have the landing gear up or down. The model is prepared for the use of atmospheric turbulence as external disturbance.

The ADMIRE is augmented with an FCS in order to provide stability and sufficient handling qualities within the operational envelope. The FCS contains a longitudinal and a lateral part. The longitudinal controller provides pitch rate control below Mach number 0.58. For Mach numbers greater than or equal to 0.62 it provides load factor control. The corner speed is close to Mach number 0.60. In the Mach number region between 0.58 and 0.62, a blending is performed. There is an α-limiter functionality active during pitch rate mode. The longitudinal controller also contains a very rudimentary speed controller. The lateral controller enables the pilot to perform initial roll control around the velocity vector of the aircraft and angle of sideslip control.

Sensor models used by the FCS are incorporated in the model, together with a 20 ms computer delay on the actuator inputs, implemented as Padé-approximations. There is also a possibility to vary some parameters and uncertainties within given tolerances, in order to facilitate the robustness analysis proposed within the GARTEUR project Flight Clearance FM(AG-11). The available uncertainties consist of inertia, aerodynamic, actuator and sensor uncertainties presented in Appendix B.

2.1 Model Data and Envelope

There is no configuration description available except for a simple schematic picture, see Figure 2.1. Aircraft configuration data used in ADMIRE are described in Table 2.1. The data gives an idea about the size of the aircraft. Suggestions for the aircraft mass and the mass distribution can be found in [1]. The mass and inertia are functions of the percentage of internal fuel onboard, and in the nominal case the mass represents 60% of fuel loaded.

The ADMIRE mass center is located at the aerodynamic reference point on the x-axis and slightly above the z-axis. There is of course a possibility to change the values of the mass parameters, i.e., the mass, mass distribution and

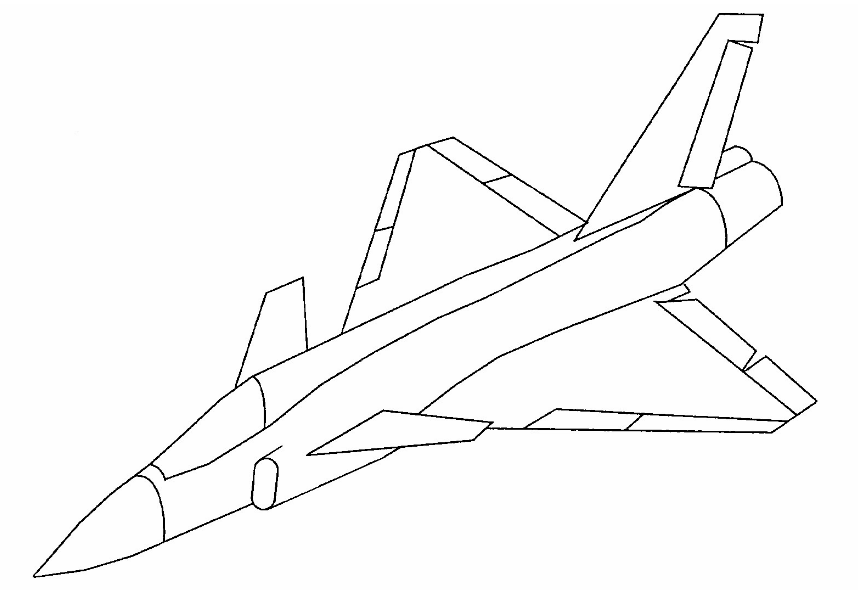


Figure 2.1: Principal layout of the configuration.

the position of the mass center, which affect the stability margin of the aircraft. If the mass properties are changed, bear in mind that the FCS is designed for the nominal model described in Table 2.1.

Parmeter:	Value:	Unit:
wing area	45.00	m^2
wing span	10.00	m
wing chord(mean)	5.20	m
Mass	9100	kg
Ix	21000	kgm^2
Iy	81000	kgm^2
Iz	101000	kgm^2
Ixz	2500	kgm^2

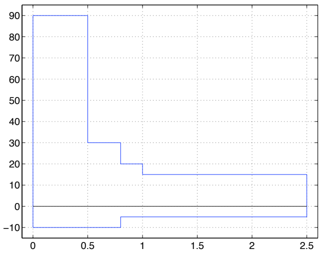
Table 2.1: Nominal configuration data.

The Generic Aerodata Model (GAM) is described in [1] and among other things there are six different validity plots given as functions of Mach number, see Figure 2.2.

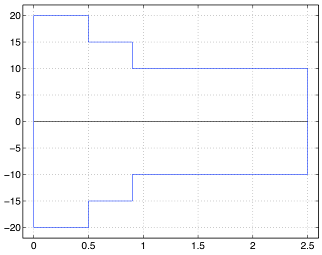
The ADMIRE flight envelope is restricted to Mach numbers less than 1.2 and altitudes below 6 km. Within the flight envelope there are additional constraints due to aerodata. The variables that have restrictions are angle of attack, angle of sideslip and the control surface deflections, as seen in Figure 2.2. Due to (assumed) structural reasons and concern for the well-being of a hypothetical pilot, the normal load factor is constrained to $-3g \leq n_z \leq +9g$ over the whole envelope.

2.2 Aircraft Dynamic Model

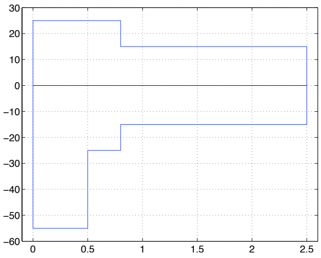
The aircraft dynamics are modeled as a set of twelve first order non-linear differential equations on the form



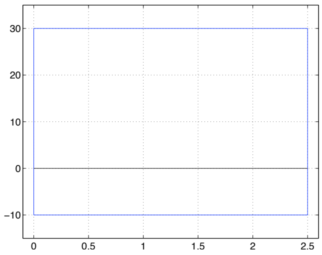
(a) Angle of attack.



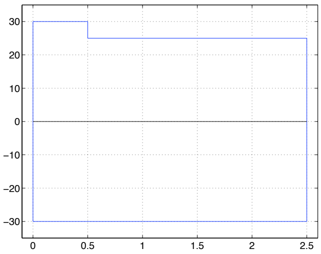
(b) Angle of sideslip.



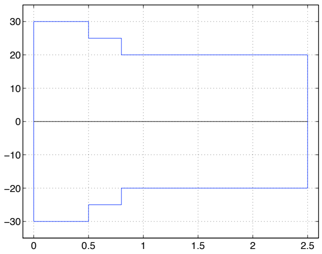
(c) Canard deflection angle.



(d) Leading edge flap deflection angle.



(e) Elevon deflection angle.



(f) Rudder deflection angle.

Figure 2.2: Envelope of the GAM aerodata model. Allowed angles of incidence and control surface deflections are inside the curves.

$$\begin{aligned} \dot{\bar{x}} &= f(\bar{x}, \bar{u}, \bar{p}) \\ \bar{y} &= g(\bar{x}, \bar{p}) \end{aligned} \tag{2.1}$$

where $\bar{x}$ is the state vector, $\bar{u}$ is the input vector, $\bar{y}$ is the output vector and $\bar{p}$ is the uncertainty parameter space vector. The state equations used are listed below

$$\dot{V}_T = (u_b \cdot \dot{u}_b + v_b \cdot \dot{v}_b + v_b \cdot \dot{v}_b)/V_T \tag{2.2}$$

$$\dot{\alpha} = (u_b \cdot \dot{w}_b - w_b \cdot \dot{u}_b)/(u_b^2 + w_b^2) \tag{2.3}$$

$$\dot{\beta} = (\dot{v}_b \cdot V_T - v_b \cdot \dot{V}_T)/(V_T^2 \cdot \cos\beta) \tag{2.4}$$

$$\dot{p}_b = (C_1 \cdot r_b + C_2 \cdot p_b) \cdot q_b + C_3 \cdot M_x + C_4 \cdot M_z \tag{2.5}$$

$$\dot{q}_b = C_5 \cdot p_b \cdot r_b - C_6(p_b^2 - r_b^2) + C_7 \cdot M_y \tag{2.6}$$

$$\dot{r}_b = (C_8 \cdot p_b - C_2 \cdot r_b)q_b + C_4 \cdot M_x + C_9 \cdot M_z \tag{2.7}$$

$$\dot{\psi} = (q_b \cdot \sin\phi + r_b \cdot \cos\phi)/\cos(\theta) \tag{2.8}$$

$$\dot{\theta} = q_b \cdot \cos\phi - r_b \cdot \sin\phi \tag{2.9}$$

$$\dot{\phi} = p_b + \tan\theta \cdot (q_b \cdot \sin\phi + r_b \cdot \cos\phi) \tag{2.10}$$

$$\begin{aligned}
\dot{x}_v &= \cos\theta\cdot\cos\psi\cdot u_b + (\sin\phi\cdot\sin\theta\cdot\cos\psi - \cos\phi\cdot\sin\psi)\cdot v_b + \\
&\quad (\cos\phi\cdot\sin\theta\cdot\cos\psi + \sin\phi\cdot\sin\psi)\cdot w_b \qquad (2.11)\\
\dot{y}_v &= \cos\theta\cdot\sin\psi\cdot u_b + (\sin\phi\cdot\sin\theta\cdot\sin\psi + \cos\phi\cdot\cos\psi)\cdot v_b + \\
&\quad (\cos\phi\cdot\sin\theta\cdot\sin\psi - \sin\phi\cdot\cos\psi)\cdot w_b \qquad (2.12)\\
\dot{z}_v &= -\sin\theta\cdot u_b + \sin\phi\cdot\cos\theta\cdot v_b + \cos\phi\cdot\cos\theta\cdot w_b \qquad (2.13)
\end{aligned}$$

where

$$\begin{aligned}
\dot{u}_B &= r_b\cdot v_b - q_b\cdot w_b - g_0\cdot\sin\theta + F_x/m \qquad (2.14)\\
\dot{v}_B &= -r_b\cdot u_b + p_b\cdot w_b + g_0\cdot\sin\phi\cdot\cos\theta + F_y/m \qquad (2.15)\\
\dot{w}_B &= q_b\cdot u_b - p_b\cdot v_b + g_0\cdot\cos\phi\cdot\cos\theta + F_z/m \qquad (2.16)
\end{aligned}$$

The output vector consists of the state variables plus additional variables defined by the equations:

$$\begin{aligned}
u_b &= V_T\cdot\cos\alpha\cdot\cos\beta \qquad (2.17)\\
v_b &= V_T\cdot\sin\beta \qquad (2.18)\\
w_b &= V_T\cdot\sin\alpha\cdot\cos\beta \qquad (2.19)\\
u_v &= \cos\theta\cdot\cos\psi\cdot u_b + (\sin\phi\cdot\sin\theta\cdot\cos\psi - \cos\phi\cdot\sin\psi)\cdot v_b + \\
&\quad (\cos\phi\cdot\sin\theta\cdot\cos\psi + \sin\phi\cdot\sin\psi)\cdot w_b \qquad (2.20)\\
v_v &= \cos\theta\cdot\sin\psi\cdot u_b + (\sin\phi\cdot\sin\theta\cdot\sin\psi + \cos\phi\cdot\cos\psi)\cdot v_b + \\
&\quad (\cos\phi\cdot\sin\theta\cdot\sin\psi - \sin\phi\cdot\cos\psi)\cdot w_b \qquad (2.21)\\
w_v &= -\sin\theta\cdot u_b + \sin\phi\cdot\cos\theta\cdot v_b + \cos\phi\cdot\cos\theta\cdot w_b \qquad (2.22)\\
n_z &= -F_{Z_{\text{aero}}}/(m\cdot g_0) \qquad (2.23)\\
n_y &= -F_{Y_{\text{aero}}}/(m\cdot g_0) \qquad (2.24)\\
M &= V_T/a(h) \qquad (2.25)\\
\gamma &= \arcsin(\cos\alpha\cdot\cos\beta\cdot\sin\theta - \\
&\quad (\sin\phi\cdot\sin\beta + \cos\phi\cdot\sin\alpha\cdot\cos\beta)\cdot\cos\theta) \qquad (2.26)\\
C_D &= C_N\cdot\sin\alpha + C_T\cdot\cos\alpha \qquad (2.27)\\
C_L &= C_N\cdot\cos\alpha - C_T\cdot\sin\alpha \qquad (2.28)
\end{aligned}$$

and

$$C_C, C_l, C_m, C_n, F_x, F_y, M_y \qquad (2.29)$$

Note that the dynamics of the aircraft is singular at $\theta = 90°$. Note also that the bank angle (ϕ) is not limited to $\pm 180°$. The equations are described in more detail in [3].

2.3 Aerodata Model

The aircraft aerodata modeling consists of aerodata tables, interpolation routines and aerodata algorithms. This is a standard way of performing aerodynamic modeling today. In these aerodata tables an interpolation is made and the six resulting aerodynamic coefficients, (C_T, C_N, C_C, C_l, C_m, C_n), are calculated.

Note that these coefficients are calculated with respect to a reference point located at 25% of the mean chord of the wing. The aerodynamic reference point coincides with the nominal c.g. of the aircraft. Further on, all of the aerodynamic coefficients are calculated with respect to a body fixed reference frame defined in Figures 2.3 and 2.4. These Figures are taken from [1].

ADMIRE is implemented in the MATLAB/SIMULINK environment as S-functions based on C-code. It should be pointed out that the original aerodata

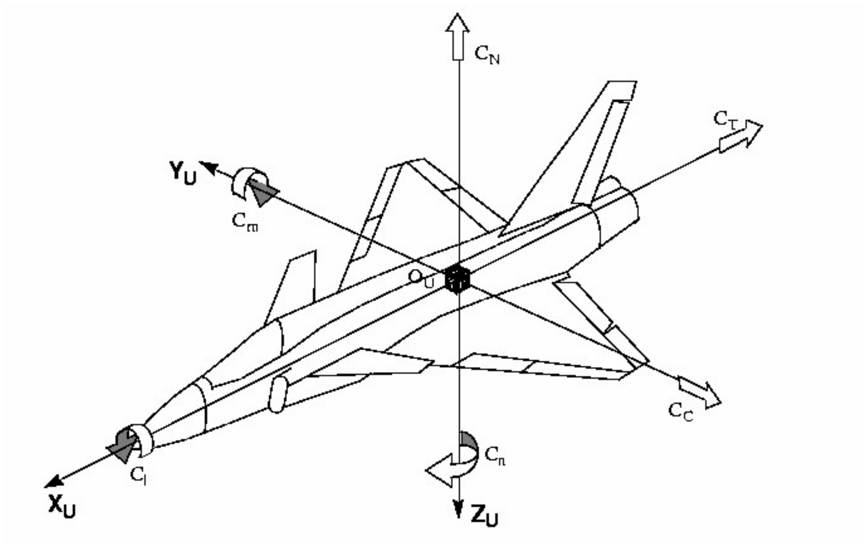


Figure 2.3: Definition of aerodynamic coefficients.

model, GAM, is valid for Mach numbers up to 2.5, altitudes up to 20 km, angles of attack up to 30° and sideslip angles up to 20°. The model has been further extended at two occasions. First the envelope was extended for angles of attack up to 90° at Mach numbers less than 0.5 for the longitudinal part only. That is, at high angles of attack the lateral motion would be governed by aerodynamic coefficients only valid at 30° angle of attack. This lead to the second extension where the lateral part of the aerodynamic data was extended, accordingly, up to 90° angles of attack. The latest work on the lateral part is quite rough and based only on assumptions on what lateral dynamics this type of aircraft might have. For instance, the aircraft is assumed to suffer from yaw instabilities at high α, when the airflow around the fin is strongly turbulent and disturbed. Further, the control efficiency of the surfaces is assumed to detoriate.

Note that the flight envelope of ADMIRE is smaller than GAM since it is constrained due to the engine model. It is valid for altitudes up to 6 km and Mach numbers up to 1.2.

In Figure 2.3, the definition of the direction of the forces and moments from the aerodata is shown. The aerodynamic forces are given in the form of body fixed normal, tangential and side forces. The aerodynamic reference point (O_U) and the centre of gravity (O_B) are given in Figure 2.4. Note that the reference point will not move, but the location of c.g. can be changed. In the nominal case these two points coincide. The deviation in c.g. from the aerodynamic reference point will give additional effects in the moment equations.

The aerodynamic model is built up in a conventional way, by interpolating in (unstructured) data tables to get the different contributions. Different aerodata tables are used at different Mach numbers. A transition is made between Mach numbers 0.4 and 0.5 and at Mach number 1.4. Note that the common notation with stability and control derivatives is not applicable all the time in this aerodata model. The aerodata contains static aeroelastic effects and coupling between lateral and longitudinal dynamics of the aircraft, i.e. C_{N_β}. The total aerodynamic forces and moments acting on the aircraft are calculated in the following way:

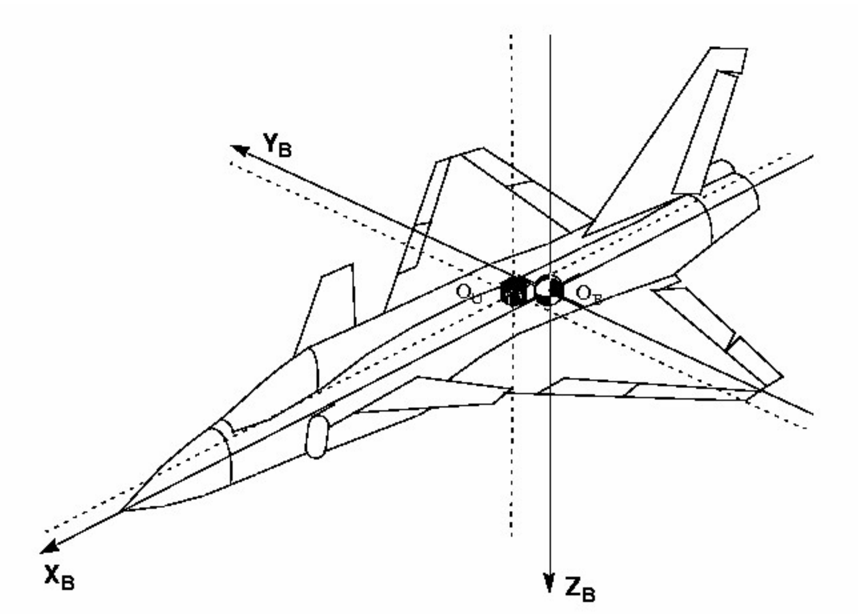


Figure 2.4: Definition of reference frames.

$$
\begin{aligned}
F_x &= \bar{q} \cdot S_{\mathrm{ref}} \cdot C_{T_{\mathrm{tot}}} && (2.30)\\
F_y &= \bar{q} \cdot S_{\mathrm{ref}} \cdot C_{C_{\mathrm{tot}}} && (2.31)\\
F_z &= -\bar{q} \cdot S_{\mathrm{ref}} \cdot C_{N_{\mathrm{tot}}} && (2.32)\\
M_x &= \bar{q} \cdot S_{\mathrm{ref}} \cdot b_{\mathrm{ref}} \cdot C_{l_{\mathrm{tot}}} - z_{cg} \cdot F_y + y_{cg} \cdot F_z && (2.33)\\
M_y &= \bar{q} \cdot S_{\mathrm{ref}} \cdot c_{\mathrm{ref}} \cdot C_{m_{\mathrm{tot}}} - x_{cg} \cdot F_z + z_{cg} \cdot F_x && (2.34)\\
M_z &= \bar{q} \cdot S_{\mathrm{ref}} \cdot b_{\mathrm{ref}} \cdot C_{n_{\mathrm{tot}}} + x_{cg} \cdot F_y - y_{cg} \cdot F_x && (2.35)
\end{aligned}
$$

2.4 Engine model

The engine model contains data in two 2-dimensional tables describing the engine thrust. The two tables contain the available thrust from the engine, one with activated afterburner and the other without. The thrust is a function of the altitude and the Mach number, see Figure 2.5.

The engine model is scaled so that the ratio between the static thrust and the maximum take-off weight of the aircraft correlates to the value of similar modern aircraft. The input to the engine is the Throttle Stick Setting (T_{ss}), which takes values between 0 and 1. At T_{ss} greater than or equal to 0.8 the afterburner is active.

Due to the time it takes to accelerate/decelerate the rotating parts of the engine, the dynamic response in the engine is modeled with a simple first-order lag filter.

$$T_{ss}(s) = \frac{0.5}{s + 0.5} \cdot T_{ss_{\mathrm{com}}} \qquad (2.36)$$

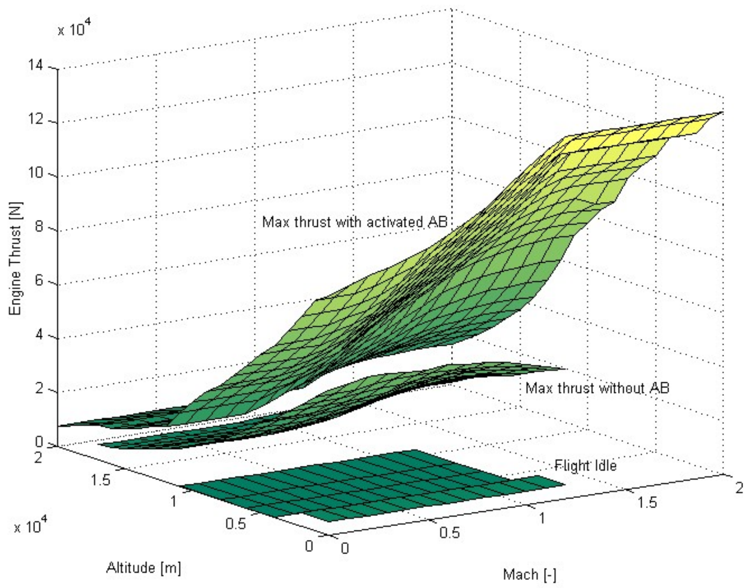


Figure 2.5: Engine thrust data.

2.5 Actuators

The actuator model that is used, is simply a first order transfer function with limited angular deflection and maximum angular rate. Note that the time constant for the leading edge flap is chosen to have a different value, compared with the other actuators. This representation of an actuator can be seen as a standard representation. It is possible to use more advanced rate- and deflection limits plus higher order transfer functions, see [4].

The available control actuators in the ADMIRE model are:

- left canard (δ_{lc})
- right canard (δ_{rc})
- left outer elevon (δ_{loe})
- left inner elevon (δ_{lie})
- right inner elevon (δ_{rie})
- right outer elevon (δ_{roe})
- leading edge flap (δ_{le})
- rudder (δ_{r})
- landing gear (δ_{ldg})
- air brake (δ_{ab})
- horizontal thrust vectoring (δ_{th})
- vertical thrust vectoring (δ_{tv})

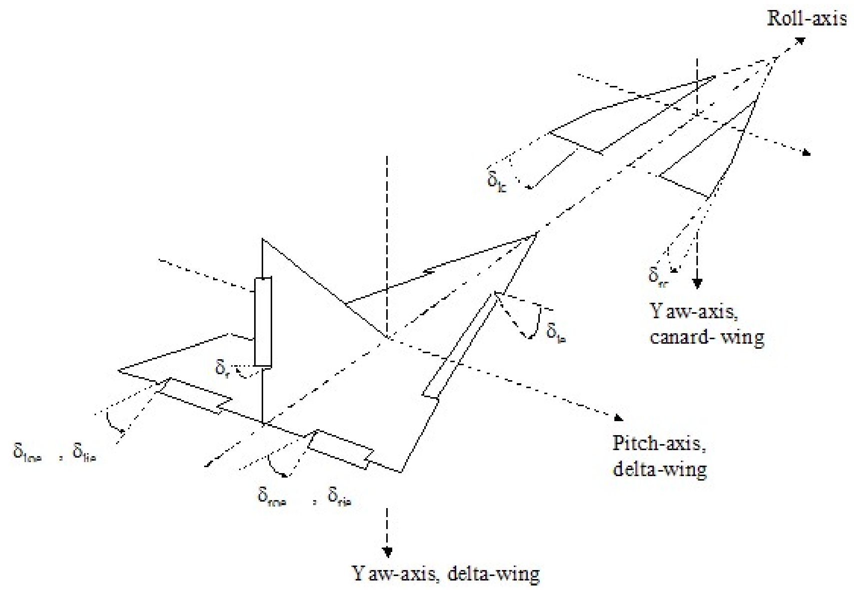


Figure 2.6: Definition of the control surface deflections.

The leading edge flap, landing gear and thrust vectoring are not used in the FCS. The sign of the actuator deflections follows the "right-hand-rule", except for the leading edge flap that has a positive deflection down. The "right-hand-rule" means that a positive deflection corresponds to a positive rotation assuming that the hinge line is parallel to respective axis in the body-fixed reference frame SB, see [1] and Figure 2.6. Note that there are four different elevons, only the outer two are drawn in the Figure 2.6. The inner and outer elevons on each side always move together in the present version of the FCS.

The maximal allowed deflections and suggestions for the angular rate of the control surfaces are given in Table 2.2. The deflection limits are defined in the model and should not be changed. Note that the maximum allowed deflections of the actuators depend on the Mach number, see Figure 2.2.

Control Surface:	Min. [°]	Max. [°]	Angular Rate [°/s]
Canard	−55	25	±50
Rudder	−30	30	±50
Elevons	−25	25	±50
Leading Edge Flap	−10	30	±20

Table 2.2: Control surface deflection limit.

2.6 Sensors

The modeling of the sensors is identical to the models of sensors in the HIRM model [5], used for the FM(AG-08) Robust Flight Control project. In the ADMIRE, there are implemented models of air data sensors (V_T, α, β, h), inertial sensors (p_b, q_b, r_b, n_z) and attitude sensors (θ, ϕ). Air data sensors:

$$\xi_{\text{sensed}}(s) = \frac{1}{1 + 0.02 \cdot s} \cdot \xi, \tag{2.37}$$

where $\xi = [V_T, \alpha, \beta, h]^T$.

Inertial sensors:

$$\xi_{\text{sensed}}(s) = \frac{1 + 0.005346 \cdot s + 0.0001903 \cdot s^2}{1 + 0.03082 \cdot s + 0.0004942 \cdot s^2} \cdot \xi \tag{2.38}$$

where $\xi = [p_b, q_b, r_b, n_z]^T$

Attitude sensors:

$$\xi_{\text{sensed}}(s) = \frac{1}{1 + 0.0323 \cdot s + 0.00104 \cdot s^2} \cdot \xi \tag{2.39}$$

where $\xi = [\theta, \phi]^T$

2.7 Model uncertainties

The parametric uncertainties of the model are configuration, aerodynamic, sensor and actuator uncertainties. The uncertain parameters of the ADMIRE are defined in Appendix B. The table contains the parameters, their nominal values, their upper and lower bounds, units and a description of the parameters. The nominal values of the parameters are stored within the model, and only the values in the range [min;max] should be changed. Due to coupling, the values in the table are valid if only one uncertainty is used, if more aerodynamic uncertainties are used simultaneously, the following corrections should be made

$$\delta_{k,2} = 0.62 \cdot \delta_{k,1}, \tag{2.40}$$
$$\delta_{k,3} = 0.46 \cdot \delta_{k,1}, \tag{2.41}$$
$$\delta_{k,4} = 0.37 \cdot \delta_{k,1}, \tag{2.42}$$

where $\delta_{k,j}$ is the k'th uncertainty variable in the case with j uncertainties. This means that if for instance δC_{m_α} and δC_{m_q} are applied simultaneously, the correct values of the uncertainties should be $0.62 \cdot \delta C_{m_\alpha}$ and $0.62 \cdot \delta C_{m_q}$.

The parametric uncertainties in the ADMIRE that are implemented into the code are presented below. The values with parameters are denoted with an asterisk (*), and the nominal values are without asterisk.

Aircraft mass:

$$m^* = (1 + \delta m) \cdot m \tag{2.43}$$

Centre of gravity position:

$$x^*_{cg} = x_{cg} + \delta x_{cg} \tag{2.44}$$
$$y^*_{cg} = y_{cg} + \delta y_{cg} \tag{2.45}$$
$$z^*_{cg} = z_{cg} + \delta z_{cg} \tag{2.46}$$

Inertial data:

$$I^*_{xx} = I_{xx} \cdot (1 + \delta I_{xx}) \tag{2.47}$$
$$I^*_{yy} = I_{yy} \cdot (1 + \delta I_{yy}) \tag{2.48}$$
$$I^*_{zz} = I_{zz} \cdot (1 + \delta I_{zz}) \tag{2.49}$$
$$I^*_{xz} = I_{xz} \cdot (1 + \delta I_{xz}) \tag{2.50}$$

Roll moment coefficients

$$C^*_{l_\beta} = C_{l_\beta} + \delta C_{l_\beta} \cdot \beta \tag{2.51}$$
$$C^*_{l_p} = C_{l_p} + \delta C_{l_p} \cdot \hat{p} \tag{2.52}$$
$$C^*_{l_{\delta_{ay}}} = C_{l_{\delta_{ay}}} + \delta C_{l_{\delta_{ay}}} \cdot \delta_{ay} \tag{2.53}$$
$$C^*_{l_{\delta_{ai}}} = C_{l_{\delta_{ai}}} + \delta C_{l_{\delta_{ai}}} \cdot \delta_{ai} \tag{2.54}$$
$$C^*_{l_{\delta r}} = C_{l_{\delta r}} + \delta C_{l_{dr}} \cdot \delta_r \tag{2.55}$$

Pitch moment coefficients:

$$\begin{aligned}
C^*_{m_\alpha} &= C_{m_\alpha} + \delta C_{m_\alpha} \cdot \alpha && (2.56)\\
C^*_{m_q} &= C_{m_q} + \delta C_{m_q} \cdot \hat{q} && (2.57)\\
C^*_{m_{\delta_n}} &= C_{m_{\delta_n}} + \delta C_{m_{\delta_n}} \cdot \delta_n && (2.58)\\
C^*_{m_{\delta_{ey}}} &= C_{m_{\delta_{ey}}} + \delta C_{m_{\delta_{ey}}} \cdot \delta_{ey} && (2.59)\\
C^*_{m_{\delta_{ei}}} &= C_{m_{\delta_{ei}}} + \delta C_{m_{\delta_{ei}}} \cdot \delta_{ei} && (2.60)
\end{aligned}$$

Yaw moment coefficients:

$$\begin{aligned}
C^*_{n_{\text{basic}}} &= C_{n_{\text{basic}}} + \delta C_{n_0} && (2.61)\\
C^*_{n_\beta} &= C_{n_\beta} + \delta C_{n_\beta} \cdot \beta && (2.62)\\
C^*_{n_r} &= C_{n_r} + \delta C_{n_r} \cdot \hat{r} && (2.63)\\
C^*_{n_{\delta_{na}}} &= C_{n_{\delta_{na}}} + \delta C_{n_{\delta_{na}}} \cdot \delta_{na} && (2.64)\\
C^*_{n_{\delta_{ay}}} &= C_{n_{\delta_{ay}}} + \delta C_{n_{\delta_{ay}}} \cdot \delta_{ay} && (2.65)\\
C^*_{n_{\delta_{ai}}} &= C_{n_{\delta_{ai}}} + \delta C_{n_{\delta_{ai}}} \cdot \delta_{ai} && (2.66)\\
C^*_{n_{\delta_r}} &= C_{n_{\delta_r}} + \delta C_{n_{\delta_r}} \cdot \delta_r && (2.67)
\end{aligned}$$

Sensors:

$$\begin{aligned}
V^*_{T_{\text{sensed}}} &= V_T + \delta_{V_{T\text{err}}} && (2.68)\\
M^*_{\text{sensed}} &= \frac{V^*_{T_{\text{sensed}}}}{a_{\text{calc}}(h^*_{\text{sensed}}, V^*_{T_{\text{sensed}}})} + \delta_{M\text{err}} && (2.69)\\
\alpha^*_{\text{sensed}} &= \frac{1}{1+0.02\cdot s}\cdot(\alpha + \delta_{\alpha\text{err}}) && (2.70)\\
\beta^*_{\text{sensed}} &= \frac{1}{1+0.02\cdot s}\cdot(\beta + \delta_{\beta\text{err}}) && (2.71)\\
h^*_{\text{sensed}} &= \frac{1}{1+0.02\cdot s}\cdot(h + \delta_{h\text{err}}) && (2.72)
\end{aligned}$$

Actuators: (The transfer functions are the same in the model for all actuators.)

$$\xi = \frac{1}{1 + (0.05 + \delta dc_{bw})\cdot s}\cdot \xi_{\text{com}} \tag{2.73}$$

where $\xi = \delta_{rc}$, δ_{lc}, δ_{roe}, δ_{rie}, δ_{lie}, δ_{loe}, δ_r. In the SIMULINK model, the actuator transfer functions are preceded by position and rate saturation blocks.

2.8 Atmospheric model

The atmosphere model is taken from [2]. Only the density and the speed of sound are calculated. The atmosphere is assumed to be dependent on the altitude only, so-called standard atmosphere.

ADMIRE is prepared for the use of atmospheric turbulence/wind. The available inputs are u_{dist}, v_{dist}, w_{dist} and p_{dist}. The first three correspond to body referenced wind disturbance in respective axis and the last is a rotation contribution around the x-axis in S_B. No model of the turbulence is delivered with the ADMIRE.

3 Flight Control System

The ADMIRE is augmented with a FCS in order to provide stability and sufficient handling qualities within the operational envelope. The FCS contains a longitudinal and a lateral part. The function of the longitudinal controller is pitch rate control (q_{com}) below Mach number 0.58 and load factor control ($n_{z_{\text{com}}}$) above Mach number 0.62. A blending function is used in the region in between, in order to switch between the two different modes. The longitudinal controller also contains a speed control ($V_{T_{\text{com}}}$). The lateral controller enables the pilot to perform roll control around the velocity vector of the aircraft ($p_{w_{\text{com}}}$) and to control the sideslip angle (β_{com}). The FCS is designed in 29 trim conditions using standard linear design methods.

The pilot control inceptors are longitudinal (F_{es}) and lateral (F_{as}) stick deflection, rudder pedal deflection (F_{rp}) and throttle stick setting (T_{ss}). For simplicity, linear stick gradients are used. Note that the maximum longitudinal stick deflection is asymmetric, i.e. it is possible for the pilot to pull a larger command than to push.

The control selector (CS) is used to distribute the three control channels, u_p, u_q and u_β, out to the seven control actuators used by the FCS. For pitch, the CS is calculated using the method proposed in [4]. A scheduling of the CS is done by using the Mach number and the altitude.

Since the flight controller is designed in a number of discrete points in the envelope, the gains in the FCS must be adjusted when the aircraft is operating between the initial design points. In ADMIRE all FCS gains and trim conditions are scheduled with the altitude and Mach number. In Figure 3.1, an example of a scheduled gain can be found.

In order to model the time delays present in a physical implementation of the control laws in an onboard computer, transport delays of 20 ms have been added to the actuators. The time delay is modeled as a second order Padé-approximation.

3.1 Longitudinal controller

The longitudinal controller has two parts, a pitch and a speed controller. The speed controller is very simple and is basically a gain and a lead filter. The controller is made to maintain the commanded speed.

The pitch controller has two different modes of functionality. At lower speeds ($M < 0.58$) the function of the controller is to minimize the tracking error in the commanded pitch rate, which is generated by the pilot. At higher speeds ($M > 0.62$) the controller tracks the commanded load factor. For Mach numbers in between, a blending is performed.

The pitch rate controller consists of a stabilizing inner loop. The pitch rate and the angle of attack are fed back to the control selector and an outer loop where the tracking error, and the integrated value of it, is fed forward to the control selector. Due to the chosen design method only the deviation values from the trimmed flight condition are fed to the gains. This means that

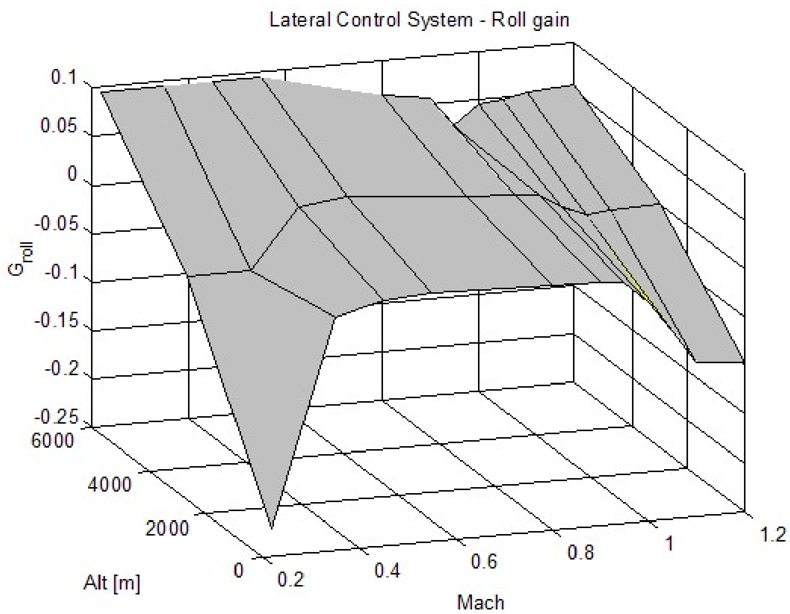


Figure 3.1: Example of scheduled gain Definition.

the controller only commands deviation from the trimmed actuator settings. The trimmed values are added in front of the actuators. The purpose of the alpha-limiter is to provide a pitch rate command to the controller when the prescribed limit of angle of attack i exceeded. How this is done is described in [5]. The load factor controller has the same principal structure as the pitch rate controller, described above, except that n_z is fed back in the outer loop and it does not contain any alpha-limiter. The longitudinal control laws were synthesized using Pole Placement Methods (PPM).

3.2 Lateral controller

The lateral control system is a so-called lateral-directional control augmentation system (CAS). The body-axis roll rate is fed back to the ailerons to modify the roll-subsidence mode. Closed-loop control of roll rate is used to reduce the variation of roll performance with flight conditions.

The inner feedback loop in the rudder channel provides -roll damping by feeding back an approximation of the wind-axis yaw rate to the rudder. The wind-axis yaw rate is washed-out so that it operates only transiently and does not contribute to a control error when steady yaw rate is present. Note that the yaw-rate feedback is equivalent to $\dot{\beta}$ feedback when ϕ and β are small.

When necessary the pilot can command a steady sideslip to the aircraft, because rudder inputs are applied via the rudder pedal gradient to the rudder actuator. The control system will tend to reject this disturbance input, so that the desirable effect of limiting the sideslipping capability will be achieved.

The outer feedback loop in the rudder channel provides Dutch-roll damping by feeding back sideslip to the rudder. The sideslip contributes to a control error and makes it possible to control the sideslip.

The cross-connection is known as the aileron-rudder interconnect (ARI). Its purpose is to provide the component of yaw rate necessary to achieve a wind-axis roll. The lateral control laws where also synthesized using PPM.

4 The ADMIRE Software description

4.1 Software requirements

MATLAB/SIMULINK Release 13. A C-compiler that MATLAB supports. For the development Microsoft Visual C/C++ 5.0 was used.

4.2 Installation of the software

In order to run the SIMULINK model, the C-file has to be compiled to a C-mex-file. First you must configure the mex options in MATLAB. Use the command:

```
>>mex -setup
```

in a MATLAB Command Window (MCW) and follow the instructions to setup the C-compiler. Second, go to the folder where the `admire_main.c` is stored and type:

```
>>mex admire_main.c
```

This will hopefully create a file named `admire_main.dll`, which is the compiled C-mex-file. (The `.dll` extension is used on Windows PC computers but varies for other platforms, for instance `.mexglx` for Linux, `.mexsol` for Solaris and `.mexmac` for Macintosh machines running OS X.) Note that `admire_main.dll` will be stored in the actual folder. Do the same with the rest of the C-files used in the SIMULINK model `admire_augmented.mdl`, i.e. `act_pos_lim.c`, `fcslateral.c`, `fcslongitudinal.c`, `fcsnz.c`, `fcsselector.c`, `fcsu0.c`, `fcsx0.c` and `machno.c`. Note that every time you perform a compilation of one of the C-files you have to be in the same folder as the chosen C-file. The C-mex-file will be stored in the actual folder. It should also be pointed out that the originally pre-compiled C-mex-files should be erased or at least renamed if you choose to make your own C-mex-files. Otherwise a possible mix-up can take place.

The file startup.m, provided by David Bennet of BAe Systems, can be used to automatically update MATLAB's search path to incorporate the below listed folders, i.e. the folders that contain the model and the supporting programs. When MATLAB is started, MATLAB automatically runs the `startup.m` file, if one exists in the directory from which MATLAB is started.

```
..\admirer4.0\ac
..\admirer4.0\ac\c
..\admirer4.0\ac\dll
..\admirer4.0\fcs\c
..\admirer4.0\fcs\dll
..\admirer4.0\linearisation
..\admirer4.0\plot
..\admirer4.0\simulink
```

```
..\admirer4.0\trimdata
..\admirer4.0\trimming
..\admirer4.0\trimming\vt
```

4.3 Trimming and linearization

The model must first be trimmed at the point in the envelope where you want to linearize it or start the simulation. Running `admtrim_sl.m` or `admtrim_aoa.m` does this. For a list of the model states, see the file `admtrim_states_aoa.m`. In this release of ADMIRE, trimming works only for straight and level flight or pull-ups with specified angle of attack, and only within the envelope.

CAUTION: If the trimming is aborted while `admire_complete_trim` is compiled, you MUST terminate it in the following manner:

```
>>admire_complete_trim([],[],[],'term')
```

possibly a number of times, before you proceed. Otherwise your following trimming results will be completely unreliable.

The programs `admtrim_sl.m` and `admtrim_aoa.m` make calls to the programs `setup_ratelims.m` and `uncertainty.m`. In Admire4.0 you always use the standard MATLAB rate-limiters with the `rlimit_*` settings given in `setup_ratelims.m`. As default, `uncertainty.m` does not add any uncertainty. You must edit it to add the characteristics you want. You can run `setup_ratelims.m` and uncertainty.m separately if you like. Edit `uncertainty.m` if you want to investigate the robustness of the aircraft control system. Edit `setup_ratelims.m` to investigate the effects of rate limits on the control surfaces.

If you want to use the linearized versions of the control system and aircraft characteristics you must linearize them at the trimmed condition. The control system and the bare aircraft are linearized separately. Note that the control selector, computer time delays and the saturators, rate limiters and actuators blocks are not included in either part of the linearization. These must be modeled or linearized separately. The file `admire_linear.mdl` shows one way of connecting the linearized control system and the linear aircraft. To linearize, first trim the model as described above, then type:

```
>>adm_lin
```

this yields the linearized control system and the linearized bare aircraft. Note that you will not get the correct coupling between the lateral and longitudinal motion when you use the linear model. (Note! If you want a linear version of the complete aircraft you can linearize the SIMULINK model `admire_linear.mdl` with linmod. You must first remove the memory block in the feedback path.)

4.4 Simulation

After you have trimmed the model (and added rate limiter data and/or uncertainties), open the SIMULINK model `admire_sim.mdl`. This is done by simply typing

```
>>admire_sim
```

Use the pull-down menus to run the simulation. In `admire_linear.mdl` the time step for simulation is set to 0.008 s. Such a short time step is required for the Padé-approximations of the time delays to work properly. The other SIMULINK models use a time step of 0.01 s. You can experiment with longer time steps if you like. To view a subset of the simulated outputs of `admire_sim.mdl` type

```
>>admire_sim_plot
```

A better plotting program for checking the trimmed condition is `trimplot.m`. You can also simulate the model `admire_linear.mdl` and plot with `admire_linear_plot.m`. If you want to compare data between `admire_sim.mdl` and `admire_linear.mdl`, use `admire_test_plot` after you have run the simulations.

4.5 Registration

If you use this model, please send your name, name of organization and e-mail address to:

`admire@foi.se`

If you register as a user we will send you updates and bug reports via email. If there are any problems, any bugs in the software or you have any questions, please contact us at the same e-mail address. Note that our resources for giving support are limited.

Bibliography

[1] H. Backström, *Report on the usage of the Generic Aerodata Model*, Saab Aircraft AB, Linköping, 1996.

[2] J-F. Magni, S. Bennani, J. Terlouw, *Robust flight control. A design challenge*, Springer-Verlag, London, 1997.

[3] B. Stevens, F. Lewis, *Aircraft Control and Simulation*, Wiley & Sons, New York, 1992.

[4] *Application of Multivariable Control Theory to Aircraft Control Laws. Final Report - Multivariable Control Design Guidelines*, Honeywell Inc., 1996.

[5] F. Amato, M. Mattei, S. Scala, L. Verde, *Robust flight control design for the HIRM (High Incidence Research Model) via linear quadratic methods*, AIAA Guidance, Navigation, and Control Conference and Exhibit, Boston, MA, Aug. 10-12, 1998.

A Algorithms for the Aerodynamic Model

The aerodynamic model is built up in a conventional way, by interpolating in (unstructured) data tables to get the different contributions. The aerodata is different for different Mach number, changes occur between 0.4 and 0.5, and at Mach 1.4. Note that the common notation with stability- and control derivatives is not applicable all the time in this aerodata model. The aerodata contains static aeroelastic effects and coupling between lateral and longitudinal dynamics of the aircraft, i.e. C_{N_β}.

Some Definitions

$$\delta_{ei} = (\delta_{lie} + \delta_{rie})/2 \tag{A.1}$$

$$\delta_{ai} = (\delta_{lie} - \delta_{rie})/2 \tag{A.2}$$

$$\delta_{ey} = (\delta_{loe} + \delta_{roe})/2 \tag{A.3}$$

$$\delta_{ay} = (\delta_{loe} - \delta_{roe})/2 \tag{A.4}$$

$$\delta_{ne} = (\delta_{lc} + \delta_{rc})/2 \tag{A.5}$$

$$\delta_{na} = (\delta_{lc} - \delta_{rc})/2 \tag{A.6}$$

$$\delta_{n} = \delta_{ne} \tag{A.7}$$

$$\delta_{e} = (\delta_{ei} + \delta_{ey})/2 \tag{A.8}$$

$$tf_{\text{low}} = \begin{cases} 10 \cdot (0.5 - M) & \text{for } 0.4 \leq \text{M} \leq 0.5 \\ 0 & \text{otherwise} \end{cases} \tag{A.9}$$

$$tf_{\text{high}} = \begin{cases} 10 \cdot (M - 0.4) & \text{for } 0.4 \leq \text{M} \leq 0.5 \\ 0 & \text{otherwise} \end{cases} \tag{A.10}$$

Tangential force coefficient

Mach ≤ 0.4:

$$C_{T_{\text{basic}}} = C_{T0}(M) + C_{T_h}(h, M) \tag{A.11}$$

$$C_{T_\alpha} = C_{T_\alpha}(\alpha) \tag{A.12}$$

$$C_{T_{\delta_{ei}}} = C_{T_{\delta_e \alpha}}(\delta_{ei}, \alpha) \cdot \delta_{ei_{\text{eff}}} \tag{A.13}$$

$$C_{T_{\delta_{ey}}} = C_{T_{\delta_e \alpha}}(\delta_{ey}, \alpha) \cdot \delta_{eo_{\text{eff}}} \tag{A.14}$$

$$C_{T_{\delta_e \delta_n}} = C_{T_{\delta_n \delta_e}}(\delta_n, \delta_e, \alpha) \tag{A.15}$$

$$C_{T_{\delta_n}} = C_{T_{\delta_n \alpha}}(\delta_n, \alpha) \tag{A.16}$$

$$C_{T_{\delta_{le}}} = C_{T_{\delta_{le} \alpha}}(\delta_{le}, \alpha) + C_{T_{\delta_{le} \delta_n \alpha}}(\delta_n, \alpha) \cdot \delta_{le}/27.0 \tag{A.17}$$

$$C_{T_{\delta_a}} = C_{T_{\delta_a \alpha}}(|\delta_{ai}|, |\alpha|) \cdot \delta_{ei_{\text{eff}}} + C_{T_{\delta_a \alpha}}(|\delta_{ay}|, |\alpha|) \cdot \delta_{eo_{\text{eff}}} \tag{A.18}$$

$$C_{T_\beta} = C_{T_\beta}(\delta_n, \alpha) \cdot C_{T_{kb}}(|\beta|) \tag{A.19}$$

$$C_{T_{\delta_r}} = C_{T_{M \delta_r}}(|\delta_r|, M) \tag{A.20}$$

$$C_T^{\text{high}} = C_{T_{\alpha 0}}^{\text{high}}(\alpha) + C_{T_{\alpha \delta_n}}^{\text{high}}(\delta_n, \alpha) + C_{T_{\alpha \delta_e}}^{\text{high}}(\delta_e, \alpha) \tag{A.21}$$

$0.4 <$ Mach < 0.5:

$$C_{T_{\text{basic}}} = C_{T0}(M) + C_{T_h}(h, M) \tag{A.22}$$

$$
\begin{aligned}
C_{T_\alpha} &= C_{T_\alpha}(\alpha)\cdot tf_{\text{low}} + C_{T_{M\alpha}}(0.5,\alpha)\cdot tf_{\text{high}} && \text{(A.23)}\\
C_{T_{\delta_{ei}}} &= C_{T_{\delta_e\alpha}}(\delta_{ei},\alpha)\cdot \delta_{ei_{\text{eff}_{\text{low}}}}\cdot tf_{\text{low}} + \\
&\quad C_{T_{M\delta_e\alpha}}(0.5,\delta_{ei},\alpha)\cdot \delta_{ei_{\text{eff}_{\text{high}}}}\cdot tf_{\text{high}} && \text{(A.24)}\\
C_{T_{\delta_{ey}}} &= C_{T_{\delta_e\alpha}}(\delta_{ey},\alpha)\cdot \delta_{eo_{\text{eff}_{\text{low}}}}\cdot tf_{\text{low}} + \\
&\quad C_{T_{M\delta_e\alpha}}(0.5,\delta_{ey},\alpha)\cdot \delta_{eo_{\text{eff}_{\text{high}}}}\cdot tf_{\text{high}} && \text{(A.25)}\\
C_{T_{\delta_e\delta_n}} &= C_{T_{\delta_n\delta_e}}(\delta_n,\delta_e,\alpha)\cdot tf_{\text{low}} && \text{(A.26)}\\
C_{T_{\delta_n}} &= C_{T_{\delta_n\alpha}}(\delta_n,\alpha)\cdot tf_{\text{low}} + C_{T_{M\delta_{na}}}(0.5,\delta_n,\alpha)\cdot tf_{\text{high}} && \text{(A.27)}\\
C_{T_{\delta_{le}}} &= (C_{T_{\delta_{le}\alpha}}(\delta_{le},\alpha) + C_{T_{\delta_{le}\delta_n\alpha}}(\delta_n,\alpha)\cdot \delta_{le}/27.0)\cdot tf_{\text{low}} + \\
&\quad C_{T_{M\delta_{le}\alpha}}(0.5,\delta_{le},\alpha)\cdot tf_{\text{high}} && \text{(A.28)}\\
C_{T_\beta} &= 0 && \text{(A.29)}\\
C_{T_{\delta_a}} &= (C_{T_{\delta_a\alpha}}(|\delta_{ai}|,|\alpha|)\cdot \delta_{ei_{\text{eff}_{\text{low}}}} + C_{T_{\delta_a\alpha}}(|\delta_{ay}|,|\alpha|)\cdot \delta_{eo_{\text{eff}_{\text{low}}}})\cdot \\
&\quad tf_{\text{low}} + (C_{T_{\delta_a M}}(|\delta_{ai}|,0.5)\cdot \delta_{ei_{\text{eff}_{\text{high}}}} + \\
&\quad C_{T_{\delta_a M}}(|\delta_{ay}|,0.5)\cdot \delta_{eo_{\text{eff}_{\text{high}}}})\cdot tf_{\text{high}} && \text{(A.30)}\\
C_{T_{\delta_r}} &= C_{T_{M\delta_r}}(|\delta_r|,M) && \text{(A.31)}
\end{aligned}
$$

Mach ≥ 0.5:

$$
\begin{aligned}
C_{T_{\text{basic}}} &= C_{T0}(M) + C_{T_h}(h,M) && \text{(A.32)}\\
C_{T_\alpha} &= C_{T_{M\alpha}}(M,\alpha) && \text{(A.33)}\\
C_{T_{\delta_{ei}}} &= C_{T_{M\delta_e\alpha}}(M,\delta_{ei},\alpha)\cdot \delta_{ei_{\text{eff}}} && \text{(A.34)}\\
C_{T_{\delta_{ey}}} &= C_{T_{M\delta_e\alpha}}(M,\delta_{ey},\alpha)\cdot \delta_{eo_{\text{eff}}} && \text{(A.35)}\\
C_{T_{\delta_e\delta_n}} &= 0 && \text{(A.36)}\\
C_{T_{\delta_n}} &= C_{T_{M\delta_n\alpha}}(M,\delta_n,\alpha) && \text{(A.37)}\\
C_{T_{\delta_{le}}} &= C_{T_{M\delta_{le}\alpha}}(M,\delta_{le},\alpha) && \text{(A.38)}\\
C_{T_\beta} &= 0 && \text{(A.39)}\\
C_{T_{\delta_a}} &= C_{T_{\delta_a M}}(|\delta_{ai}|,M)\cdot \delta_{ei_{\text{eff}}} + C_{T_{\delta_a M}}(|\delta_{ay}|,M)\cdot \delta_{eo_{\text{eff}}} && \text{(A.40)}\\
C_{T_{\delta_r}} &= C_{T_{M\delta_r}}(|\delta_r|,M) && \text{(A.41)}\\
C_{T_{\text{tot}}} &= C_{T_{\text{basic}}} + C_{T_\alpha} + C_{T_{\delta_{ei}}} + C_{T_{\delta_{ey}}} + C_{T_{\delta_e\delta_n}} + C_{T_{\delta_n}} + \\
&\quad C_{T_{\delta_{le}}} + C_{T_\beta} + C_{T_{\delta_a}} + C_{T_{\delta_r}} + C_T^{\text{high}} && \text{(A.42)}
\end{aligned}
$$

Normal force coefficient Mach ≤ 0.4:

$$
\begin{aligned}
C_{N_{\text{basic}}} &= C_{N_0}(M) + C_{N_{e0}}(qa_{\text{corr}},M) && \text{(A.43)}\\
C_{N_\alpha} &= C_{N_{\delta_e\alpha}}(0,\alpha)\cdot C_{N_{e\alpha}}(qa_{\text{corr}},M) && \text{(A.44)}\\
C_{N_{\delta_{ei}}} &= (C_{N_{\delta_e\alpha}}(\delta_{ei},\alpha) - C_{N_{\delta_e\alpha}}(0,\alpha))\cdot \delta_{ei_{\text{eff}}}\cdot C_{N_{e\delta_{ei}}}(qa_{\text{corr}},M) && \text{(A.45)}\\
C_{N_{\delta_{ey}}} &= (C_{N_{\delta_e\alpha}}(\delta_{ey},\alpha) - C_{N_{\delta_e\alpha}}(0,\alpha))\cdot \delta_{eo_{\text{eff}}}\cdot C_{N_{e\delta_{ey}}}(qa_{\text{corr}},M) && \text{(A.46)}\\
C_{N_{\delta_e\delta_n}} &= C_{N_{\delta_n\delta_e}}(\delta_n,\delta_e,\alpha) && \text{(A.47)}\\
C_{N_{\delta_n}} &= C_{N_{\delta_n\alpha}}(\delta_n,\alpha)\cdot C_{N_{e\delta_n}}(qa_{\text{corr}},M) && \text{(A.48)}\\
C_{N_{\delta_{le}}} &= (C_{N_{\delta_{le}\alpha}}(\alpha) + C_{N_{\delta_{le}\delta_n\alpha}}(\delta_n,\alpha) + C_{N_{\delta_{le}\delta_e\alpha}}(\delta_e,\alpha))\cdot \delta_{le}/27.0 && \text{(A.49)}\\
C_{N_{cai}} &= C_{N_{cai}}(cai,\alpha) && \text{(A.50)}\\
C_{N_\beta} &= C_{N_\beta}(\delta_n,\alpha)\cdot C_{N_{kb}}(|\beta|) && \text{(A.51)}\\
C_{N_{\dot\alpha}} &= C_{N_{\dot\alpha\alpha M}}(|\alpha|,M)\cdot \dot\alpha && \text{(A.52)}\\
C_{N_q} &= C_{N_{q\alpha}}(|\alpha|)\cdot q_c\cdot C_{N_{eq}}(qa_{\text{corr}},M) && \text{(A.53)}\\
C_{N_{n_z}} &= C_{N_{en_z}}(qa_{\text{corr}},M)\cdot (n_z - 1) && \text{(A.54)}\\
C_{N_{\dot q}} &= C_{N_{e\dot q}}(qa_{\text{corr}},M)\cdot \dot q && \text{(A.55)}
\end{aligned}
$$

$$C_N^{\text{high}} = C_{N_{\alpha 0}}^{\text{high}}(\alpha) + C_{N_{\alpha\delta_n}}^{\text{high}}(\delta_n, \alpha) + C_{N_{\alpha\delta_e}}^{\text{high}}(\delta_e, \alpha) \tag{A.56}$$

$0.4 <$ Mach < 0.5:

$$\begin{aligned}
C_{N_{\text{basic}}} &= C_{N0}(M) + C_{N_{e0}}(qa_{\text{corr}}, M) && \text{(A.57)}\\
C_{N_\alpha} &= (C_{N_{\delta_e\alpha}}(0,\alpha) \cdot tf_{\text{low}} + \\
&\quad C_{N_{M\delta_e\alpha}}(0.5, 0, \alpha) \cdot tf_{\text{high}}) \cdot C_{N_{e\alpha}}(qa_{\text{corr}}, M) && \text{(A.58)}\\
C_{N_{\delta_{ei}}} &= ((C_{N_{\delta_e\alpha}}(\delta_{ei},\alpha) - C_{N_{\delta_e\alpha}}(0,\alpha)) \cdot tf_{\text{low}} + (C_{N_{M\delta_e\alpha}}(0.5, \delta_{ei}, \alpha) - \\
&\quad C_{N_{M\delta_e\alpha}}(0.5, 0, \alpha)) \cdot tf_{\text{high}}) \cdot \delta_{ei_{\text{eff}}} \cdot C_{N_{e\delta_{ei}}}(qa_{\text{corr}}, M) && \text{(A.59)}\\
C_{N_{\delta_{ey}}} &= ((C_{N_{\delta_e\alpha}}(\delta_{ey},\alpha) - C_{N_{\delta_e\alpha}}(0,\alpha)) \cdot tf_{\text{low}} + (C_{N_{M\delta_e\alpha}}(0.5, \delta_{ey}, \alpha) - \\
&\quad C_{N_{M\delta_e\alpha}}(0.5, 0, \alpha)) \cdot tf_{\text{high}}) \cdot \delta_{eo_{\text{eff}}} \cdot C_{N_{e\delta_{ey}}}(qa_{\text{corr}}, M) && \text{(A.60)}\\
C_{N_{\delta_e\delta_n}} &= C_{N_{\delta_n\delta_e}}(\delta_n, \delta_e, \alpha) \cdot tf_{\text{low}} && \text{(A.61)}\\
C_{N_{\delta_n}} &= (C_{N_{\delta_n\alpha}}(\delta_n,\alpha) \cdot tf_{\text{low}} + \\
&\quad C_{N_{\delta_n h}}(\alpha, \delta_n, 0.5) \cdot tf_{\text{high}}) \cdot C_{N_{e\delta_n}}(qa_{\text{corr}}, M) && \text{(A.62)}\\
C_{N_{\delta_{le}}} &= ((C_{N_{\delta_{le}\alpha}}(\alpha) + C_{N_{\delta_{le}\delta_n\alpha}}(\delta_n,\alpha) + C_{N_{\delta_{le}\delta_e\alpha}}(\delta_e,\alpha)) \cdot \delta_{le}/27.0) \cdot \\
&\quad tf_{\text{low}} + C_{N_{M\delta_{le}\alpha}}(0.5, \delta_{le}, \alpha) \cdot tf_{\text{high}} && \text{(A.63)}\\
C_{N_{cai}} &= C_{N_{cai}}(cai, \alpha) && \text{(A.64)}\\
C_{N_\beta} &= C_{N_\beta}(\delta_n, \alpha) \cdot C_{N_{kb}}(|\beta|) \cdot tf_{\text{low}} && \text{(A.65)}\\
C_{N_{al\dot{p}ha}} &= C_{N_{\dot\alpha\alpha M}}(|\alpha|, M) \cdot \dot\alpha && \text{(A.66)}\\
C_{N_q} &= (C_{N_{q\alpha}}(|\alpha|) \cdot tf_{\text{low}} + C_{N_{q\alpha M}}(\alpha, 0.5) \cdot tf_{\text{high}}) \cdot q_c \cdot \\
&\quad C_{N_{eq}}(qa_{\text{corr}}, M) && \text{(A.67)}\\
C_{N_{n_z}} &= C_{N_{en_z}}(qa_{\text{corr}}, M) \cdot (n_z - 1) && \text{(A.68)}\\
C_{N_{\dot q}} &= C_{N_{e\dot q}}(qa_{\text{corr}}, M) \cdot \dot q && \text{(A.69)}
\end{aligned}$$

Mach ≥ 0.5:

$$\begin{aligned}
C_{N_{\text{basic}}} &= C_{N0}(M) + C_{N_{e0}}(qa_{\text{corr}}, M) && \text{(A.70)}\\
C_{N_\alpha} &= C_{N_{M\delta_e\alpha}}(M, 0, \alpha) \cdot C_{N_{e\alpha}}(qa_{\text{corr}}, M) && \text{(A.71)}\\
C_{N_{\delta_{ei}}} &= (C_{N_{M\delta_e\alpha}}(M, \delta_{ei}, \alpha) - C_{N_{M\delta_e\alpha}}(M, 0, \alpha)) \cdot \\
&\quad \delta_{ei_{\text{eff}}} \cdot C_{N_{e\delta_{ei}}}(qa_{\text{corr}}, M) && \text{(A.72)}\\
C_{N_{\delta_{ey}}} &= (C_{N_{M\delta_e\alpha}}(M, \delta_{ey}, \alpha) - C_{N_{M\delta_e\alpha}}(M, 0, \alpha)) \cdot \\
&\quad \delta_{eo_{\text{eff}}} \cdot C_{N_{e\delta_{ey}}}(qa_{\text{corr}}, M) && \text{(A.73)}\\
C_{N_{\delta_e\delta_n}} &= 0 && \text{(A.74)}\\
C_{N_{\delta_n}} &= C_{N_{\delta_n h}}(\alpha, \delta_n, M) \cdot C_{N_{e\delta_n}}(qa_{\text{corr}}, M) && \text{(A.75)}\\
C_{N_{\delta_{le}}} &= C_{N_{M\delta_{le}\alpha}}(M, \delta_{le}, \alpha) && \text{(A.76)}\\
C_{N_{cai}} &= C_{N_{cai}}(cai, \alpha) && \text{(A.77)}\\
C_{N_\beta} &= 0 && \text{(A.78)}\\
C_{N_{\dot\alpha}} &= C_{N_{\dot\alpha\alpha M}}(|\alpha|, M) \cdot \dot\alpha && \text{(A.79)}\\
C_{N_q} &= C_{N_{q\alpha M}}(\alpha, M) \cdot q_c \cdot C_{N_{eq}}(qa_{\text{corr}}, M) && \text{(A.80)}\\
C_{N_{n_z}} &= C_{N_{en_z}}(qa_{\text{corr}}, M) \cdot (n_z - 1) && \text{(A.81)}\\
C_{N_{\dot q}} &= C_{N_{e\dot q}}(qa_{\text{corr}}, M) \cdot \dot q && \text{(A.82)}\\
C_{N_{\text{tot}}} &= C_{N_{\text{basic}}} + C_{N_\alpha} + C_{N_{\delta_{ei}}} + C_{N_{\delta_{ey}}} + C_{N_{\delta_e\delta_n}} + C_{N_{\delta_n}} + C_{N_{\delta_{le}}} + \\
&\quad C_{N_{cai}} + C_{N_\beta} + C_{N_{\dot\alpha}} + C_{N_q} + C_{N_{n_z}} + C_{N_{qd}} + C_N^{\text{high}} && \text{(A.83)}
\end{aligned}$$

Side force coefficient Mach ≤ 0.4:

$$C_{C_\beta} = C_{C_{\beta\alpha}}(|\beta|, \alpha) \cdot \text{sign}(\beta) \cdot C_{C_{e\beta}}(qa_{\text{corr}}, M) \tag{A.84}$$

$$
\begin{aligned}
C_{C_{\beta\delta_e}} &= (C_{C_{\delta_e\beta}}(|\beta|,\delta_{ei},\alpha)\cdot\delta_{ei_{\text{eff}}} + C_{C_{\delta_e\beta}}(|\beta|,\delta_{ey},\alpha)\cdot\delta_{eo_{\text{eff}}})\cdot \\
&\quad \text{sign}(\beta) && \text{(A.85)} \\
C_{C_{\beta\delta_n}} &= C_{C_{\delta_n\beta}}(|\beta|,\delta_n,\alpha)\cdot\text{sign}(\beta) && \text{(A.86)} \\
C_{C_{\beta\delta_{le}}} &= C_{C_{\delta_{le}\beta}}(\delta_{le},|\beta|,\alpha)\cdot\text{sign}(\beta) && \text{(A.87)} \\
C_{C_{\beta cai}} &= C_{C_{\beta cai}}(cai,\alpha)\cdot\beta && \text{(A.88)} \\
C_{C_{\delta_r}} &= C_{C_{\beta\delta_r\alpha}}(|\beta|,\delta_r,\alpha)\cdot C_{C_{e\delta_r}}(qa_{\text{corr}},M) && \text{(A.89)} \\
C_{C_{\delta_{ai}}} &= (C_{C_{\delta_a\alpha}}(|\delta_{ai}|,\alpha)\cdot\text{sign}(\delta_{ai}) + (C_{C_{\delta_e\alpha}}(\delta_{ei},\alpha) - \\
&\quad C_{C_{\delta_e\alpha}}(0,\alpha))\cdot\delta_{ai})\cdot\delta_{ei_{\text{eff}}}\cdot C_{C_{e\delta_{ai}}}(qa_{\text{corr}},M) && \text{(A.90)} \\
C_{C_{\delta_{ai}\beta}} &= C_{C_{\delta_a\beta\alpha}}(|\alpha|)\cdot(|\delta_{ai}|/30.0)\cdot(|\beta|/20.0)\cdot\delta_{ei_{\text{eff}}} && \text{(A.91)} \\
C_{C_{\delta_{ay}}} &= (C_{C_{\delta_a\alpha}}(|\delta_{ay}|,\alpha)\cdot\text{sign}(\delta_{ay}) + (C_{C_{\delta_e\alpha}}(\delta_{ey},\alpha) - \\
&\quad C_{C_{\delta_e\alpha}}(0,\alpha))\cdot\delta_{ay})\cdot\delta_{eo_{\text{eff}}} + C_{C_{e\delta_{ay}}}(qa_{\text{corr}},M)\cdot\delta_{ay} && \text{(A.92)} \\
C_{C_{\delta_{ay}\beta}} &= C_{C_{\delta_a\beta\alpha}}(|\alpha|)\cdot(|\delta_{ay}|/30.0)\cdot(|\beta|/20.0)\cdot\delta_{ey_{\text{eff}}} && \text{(A.93)} \\
C_{C_{\delta_{na}}} &= C_{C_{\delta_{na}\alpha}}(\delta_{ne},\alpha)\cdot\delta_{na} && \text{(A.94)} \\
C_{C_{\dot\beta}} &= C_{C_{\dot\beta l}}(\alpha)\cdot\dot\beta && \text{(A.95)} \\
C_{C_p} &= C_{C_{p\alpha l}}(\alpha)\cdot p_c && \text{(A.96)} \\
C_{C_{p\beta}} &= C_{C_{p\beta\alpha}}(|\beta|,\alpha)\cdot p_c && \text{(A.97)} \\
C_{C_r} &= C_{C_{r\alpha l}}(\delta_n,\alpha)\cdot r_c && \text{(A.98)} \\
C_{C_{r\beta}} &= C_{C_{r\beta\alpha}}(|\beta|,|\alpha|)\cdot r_c && \text{(A.99)}
\end{aligned}
$$

$0.4 <$ Mach < 0.5:

$$
\begin{aligned}
C_{C_\beta} &= (C_{C_{\beta\alpha}}(|\beta|,\alpha)\cdot\text{sign}(\beta)\cdot tf_{\text{low}} + \\
&\quad C_{C_{\beta M\alpha}}(0.5,\alpha)\cdot\beta\cdot tf_{\text{high}})\cdot C_{C_{e\beta}}(qa_{\text{corr}},M) && \text{(A.100)} \\
C_{C_{\beta\delta_e}} &= (C_{C_{\delta_e\beta}}(|\beta|,\delta_{ei},\alpha)\cdot\delta_{ei_{\text{eff}}} + C_{C_{\delta_e\beta}}(|\beta|,\delta_{ey},\alpha)\cdot\delta_{eo_{\text{eff}}})\cdot\text{sign}(\beta) && \text{(A.101)} \\
C_{C_{\beta\delta_n}} &= C_{C_{\delta_n\beta}}(|\beta|,\delta_n,\alpha)\cdot\text{sign}(\beta) && \text{(A.102)} \\
C_{C_{\beta\delta_{le}}} &= C_{C_{\delta_{le}\beta}}(\delta_{le},|\beta|,\alpha)\cdot\text{sign}(\beta)\cdot tf_{\text{low}} + \\
&\quad C_{C_{\beta\delta_{le}}}(0.5,\alpha)\cdot\beta\cdot(\delta_{le}/27.0)\cdot tf_{\text{high}} && \text{(A.103)} \\
C_{C_{\beta cai}} &= C_{C_{\beta cai}}(cai,\alpha)\cdot\beta && \text{(A.104)} \\
C_{C_{\delta_r}} &= (C_{C_{\beta\delta_r\alpha}}(|\beta|,\delta_r,\alpha)\cdot tf_{\text{low}} + \\
&\quad C_{C_{\delta_r\alpha M}}(\alpha,0.5)\cdot\delta_r\cdot tf_{\text{high}})\cdot C_{C_{e\delta_r}}(qa_{\text{corr}},M) && \text{(A.105)} \\
C_{C_{\delta_{ai}}} &= ((C_{C_{\delta_a\alpha}}(|\delta_{ai},\alpha)\cdot\text{sign}(\delta_{ai}) + (C_{C_{\delta_e\alpha}}(\delta_{ei},\alpha) - C_{C_{\delta_e\alpha}}(0,\alpha))\cdot\delta_{ai})\cdot \\
&\quad tf_{\text{low}} + (C_{C_{M\delta_a\alpha}}(0.5,|\delta_{ai}|,\alpha)\cdot\text{sign}(\delta_{ai}) + (C_{C_{\delta_a}}(0.5,\delta_{ei},\alpha) - \\
&\quad C_{C_{\delta_a}}(0.5,0,\alpha))\cdot\delta_{ai})\cdot tf_{\text{high}})\cdot\delta_{ei_{\text{eff}}}\cdot C_{C_{e\delta_{ai}}}(qa_{\text{corr}},M) && \text{(A.106)} \\
C_{C_{\delta_{ai}\beta}} &= C_{C_{\delta_a\beta\alpha}}(|\alpha|)\cdot(|\delta_{ai}|/30.0)\cdot(|\beta|/20.0)\cdot\delta_{ei_{\text{eff}}}\cdot tf_{\text{low}} && \text{(A.107)} \\
C_{C_{\delta_{ay}}} &= ((C_{C_{\delta_a\alpha}}(|\delta_{ay},\alpha)\cdot\text{sign}(\delta_{ay}) + (C_{C_{\delta_e\alpha}}(\delta_{ey},\alpha) - C_{C_{\delta_e\alpha}}(0,\alpha))\cdot\delta_{ay})\cdot \\
&\quad tf_{\text{low}} + (C_{C_{M\delta_a\alpha}}(0.5,|\delta_{ay}|,\alpha)\cdot\text{sign}(\delta_{ay}) + (C_{C_{\delta_a}}(0.5,\delta_{ey},\alpha) - \\
&\quad C_{C_{\delta_a}}(0.5,0,\alpha))\cdot\delta_{ay})\cdot tf_{\text{high}})\cdot\delta_{eo_{\text{eff}}} + C_{C_{e\delta_{ay}}}(qa_{\text{corr}},M)\cdot \\
&\quad \delta_{ay} && \text{(A.108)} \\
C_{C_{\delta_{ay}\beta}} &= C_{C_{\delta_a\beta\alpha}}(|\alpha|)\cdot(|\delta_{ay}|/30.0)\cdot(|\beta|/20.0)\cdot\delta_{eo_{\text{eff}}}\cdot tf_{\text{low}} && \text{(A.109)} \\
C_{C_{\delta_{na}}} &= (C_{C_{\delta_{na}\alpha}}(\delta_{ne},\alpha)\cdot tf_{\text{low}} + C_{C_{\delta_{na}\alpha M}}(\alpha,0.5)\cdot tf_{\text{high}})\cdot\delta_{na} && \text{(A.110)} \\
C_{C_{\dot\beta}} &= (C_{C_{\dot\beta l}}(\alpha)\cdot tf_{\text{low}} + C_{C_{\dot\beta h}}(\alpha,0.5)\cdot tf_{\text{high}})\cdot\dot\beta && \text{(A.111)} \\
C_{C_p} &= (C_{C_{p\alpha}}(\alpha)\cdot tf_{\text{low}} + C_{C_{p\alpha M}}(\alpha,0.5)\cdot tf_{\text{high}})\cdot p_c && \text{(A.112)} \\
C_{C_{p\beta}} &= C_{C_{p\beta\alpha}}(|\beta|,\alpha)\cdot p_c\cdot tf_{\text{low}} && \text{(A.113)} \\
C_{C_r} &= (C_{C_{r\alpha}}(\delta_n,\alpha)\cdot tf_{\text{low}} + C_{C_{rM}}(0.5)\cdot tf_{\text{high}})\cdot r_c\cdot \\
&\quad C_{C_{er}}(qa_{\text{corr}},M) && \text{(A.114)} \\
C_{C_{r\beta}} &= C_{C_{r\beta\alpha}}(|\beta|,|\alpha|)\cdot r_c\cdot tf_{\text{low}} && \text{(A.115)}
\end{aligned}
$$

$0.5 \leq$ Mach ≤ 1.4:

$$
\begin{aligned}
C_{C_\beta} &= C_{C_{\beta M\alpha}}(M,\alpha)\cdot\beta\cdot C_{C_{e\beta}}(qa_{\text{corr}},M) && \text{(A.116)}\\
C_{C_{\beta\delta_e}} &= (C_{C_{\delta_e\beta}}(|\beta|,\delta_{ei},\alpha)\cdot\delta_{ei_{\text{eff}}}+C_{C_{\delta_e\beta}}(|\beta|,\delta_{ey},\alpha)\cdot\delta_{eo_{\text{eff}}})\cdot\\
&\quad \text{sign}(\beta)\cdot C_{C_{bkM}} && \text{(A.117)}\\
C_{C_{\beta\delta_n}} &= C_{C_{\delta_n\beta}}(|\beta|,\delta_n,\alpha)\cdot\text{sign}(\beta) && \text{(A.118)}\\
C_{C_{\beta\delta_{le}}} &= C_{C_{\beta\delta_{le}}}(M,\alpha)\cdot\beta\cdot(\delta_{le}/27.0) && \text{(A.119)}\\
C_{C_{\beta cai}} &= C_{C_{\beta cai}}(cai,\alpha)\cdot\beta && \text{(A.120)}\\
C_{C_{\delta_r}} &= C_{C_{\delta_r\alpha M}}(\alpha,M)\cdot\delta_r\cdot C_{C_{e\delta_r}}(qa_{\text{corr}},M) && \text{(A.121)}\\
C_{C_{\delta_{ai}}} &= (C_{C_{M\delta_a\alpha}}(M,|\delta_{ai}|,\alpha)\cdot\text{sign}(\delta_{ai})+(C_{C_{\delta_a}}(M,\delta_{ei},\alpha)-\\
&\quad C_{C_{\delta_a}}(M,0,\alpha))\cdot\delta_{ai})\cdot\delta_{ei_{\text{eff}}}\cdot C_{C_{e\delta_{ai}}}(qa_{\text{corr}},M) && \text{(A.122)}\\
C_{C_{\delta_{ai}\beta}} &= 0 && \text{(A.123)}\\
C_{C_{\delta_{ay}}} &= (C_{C_{M\delta_a\alpha}}(M,|\delta_{ay}|,\alpha)\cdot\text{sign}(\delta_{ay})+(C_{C_{\delta_a}}(M,\delta_{ey},\alpha)-\\
&\quad C_{C_{\delta_a}}(M,0,\alpha))\cdot\delta_{ay})\cdot\delta_{eo_{\text{eff}}}+C_{C_{e\delta_{ay}}}(qa_{\text{corr}},M)\cdot\delta_{ay} && \text{(A.124)}\\
C_{C_{\delta_{ay}\beta}} &= 0 && \text{(A.125)}\\
C_{C_{\delta_{na}}} &= C_{C_{\delta_{na}\alpha M}}(\alpha,M)\cdot\delta_{na} && \text{(A.126)}\\
C_{C_{\dot\beta}} &= C_{C_{\dot\beta h}}(\alpha,M)\cdot\dot\beta && \text{(A.127)}\\
C_{C_p} &= C_{C_{p\alpha M}}(\alpha,M)\cdot p_c && \text{(A.128)}\\
C_{C_{p\beta}} &= 0 && \text{(A.129)}\\
C_{C_r} &= C_{C_{rM}}(M)\cdot r_c\cdot C_{C_{er}}(qa_{\text{corr}},M) && \text{(A.130)}\\
C_{C_{r\beta}} &= 0 && \text{(A.131)}\\
C_{C_{\text{tot}}} &= C_{C_\beta}+C_{C_{\beta\delta_e}}+C_{C_{\beta\delta_n}}+C_{C_{\beta\delta_{le}}}+C_{C_{\beta cai}}+C_{C_{\delta_r}}+C_{C_{\delta_{ai}}}+\\
&\quad C_{C_{\delta_{ai}\beta}}+C_{C_{\delta_{ay}}}+C_{C_{\delta_{ay}\beta}}+C_{C_{\delta_{na}}}+C_{C_{\dot\beta}}+C_{C_p}+C_{C_{p\beta}}+\\
&\quad C_{C_r}+C_{C_{r\beta}} && \text{(A.132)}
\end{aligned}
$$

Rolling moment coefficient Mach ≤ 0.4:

$$
\begin{aligned}
C_{l_{\text{basic}}} &= C_{l0}(|\alpha|) && \text{(A.133)}\\
C_{l_\beta} &= C_{l_{\beta\alpha}}(|\beta|,\alpha)\cdot\text{sign}(\beta)+C_{l_{e\beta}}(qa_{\text{corr}},M)\cdot\beta && \text{(A.134)}\\
C_{l_{\beta\delta_e}} &= (C_{l_{\delta_e\beta}}(|\beta|,\delta_{ei},\delta_n,\alpha)\cdot\delta_{ei_{\text{eff}}}+\\
&\quad C_{l_{\delta_e\beta}}(|\beta|,\delta_{ey},\delta_n,\alpha)\cdot\delta_{eo_{\text{eff}}})\cdot\text{sign}(\beta) && \text{(A.135)}\\
C_{l_{\beta\delta_n}} &= C_{l_{\delta_n\beta}}(|\beta|,\delta_n,\alpha)\cdot\text{sign}(\beta) && \text{(A.136)}\\
C_{l_{\beta\delta_{le}}} &= (C_{l_{\delta_{le}\beta}}(\delta_{le},|\beta|,\delta_{ei},\alpha)\cdot\delta_{ei_{\text{eff}}}+\\
&\quad C_{l_{\delta_{le}\beta}}(\delta_{le},|\beta|,\delta_{ey},\alpha)\cdot\delta_{eo_{\text{eff}}})\cdot\text{sign}(\beta) && \text{(A.137)}\\
C_{l_{\delta_r}} &= C_{l_{\beta\delta_r\alpha}}(|\beta|,\delta_r,\alpha)\cdot C_{l_{e\delta_r}}(qa_{\text{corr}},M) && \text{(A.138)}\\
C_{l_{\delta_{ai}}} &= (C_{l_{\delta_a\alpha}}(|\delta_{ai}|,\alpha)\cdot\text{sign}(\delta_{ai})+(C_{l_{\delta_a l}}(\delta_{ei},\alpha)-\\
&\quad C_{l_{\delta_a l}}(0,\alpha))\cdot\delta_{ai})\cdot\delta_{ei_{\text{eff}}}\cdot C_{l_{e\delta_{ai}}}(qa_{\text{corr}},M) && \text{(A.139)}\\
C_{l_{\delta_{ai}\beta}} &= C_{l_{\delta_a\beta\alpha}}(|\alpha|)\cdot(|\delta_{ai}|/30.0)\cdot(|\beta|/20.0)\cdot\delta_{ei_{\text{eff}}} && \text{(A.140)}\\
C_{l_{\delta_{ay}}} &= (C_{l_{\delta_a\alpha}}(|\delta_{ay}|,\alpha)\cdot\text{sign}(\delta_{ay})+(C_{l_{\delta_a l}}(\delta_{ey},\alpha)-\\
&\quad C_{l_{\delta_a l}}(0,\alpha))\cdot\delta_{ay})\cdot\delta_{eo_{\text{eff}}}\cdot C_{l_{e\delta_{ay}}}(qa_{\text{corr}},M) && \text{(A.141)}\\
C_{l_{\delta_{ay}\beta}} &= C_{l_{\delta_a\beta\alpha}}(|\alpha|)\cdot(|\delta_{ay}|/30.0)\cdot(|\beta|/20.0)\cdot\delta_{eo_{\text{eff}}} && \text{(A.142)}\\
C_{l_{\delta_{na}}} &= C_{l_{\delta_{na}\alpha}}(\delta_{ne},\alpha)\cdot\delta_{na} && \text{(A.143)}\\
C_{l_{\dot\beta}} &= C_{l_{\dot\beta l}}(\alpha)\cdot\dot\beta && \text{(A.144)}\\
C_{l_p} &= C_{l_{p\alpha l}}(\delta_n,\alpha)\cdot p_c\cdot C_{n_{ep}}(qa_{\text{corr}},M) && \text{(A.145)}\\
C_{n_{p\beta}} &= C_{l_{p\beta\alpha}}(|\beta|,\alpha)\cdot p_c && \text{(A.146)}\\
C_{l_r} &= C_{l_{r\alpha l}}(\delta_n,\alpha)\cdot r_c && \text{(A.147)}\\
C_{l_{r\beta}} &= C_{l_{r\beta\alpha}}(|\beta|,\alpha)\cdot r_c && \text{(A.148)}
\end{aligned}
$$

$$C_{l_{r\delta_e}} = C_{l_{r\delta_e M}}(M) \cdot C_{l_{rk\alpha}}(|\alpha|) \cdot (\delta_{ei_{\text{eff}}} \cdot \delta_{ei}/30.0 + \delta_{eo_{\text{eff}}} \cdot \delta_{ey}/30.0) \cdot r_c \tag{A.149}$$

$0.4 < \text{Mach} < 0.5$:

$$C_{l_{\text{basic}}} = C_{l0}(|\alpha|) \cdot tf_{\text{low}} \tag{A.150}$$

$$C_{l_\beta} = C_{l_{\beta\alpha l}}(|\beta|, \alpha) \cdot \text{sign}(\beta) \cdot tf_{\text{low}} + C_{l_{\beta M\alpha}}(0.5, \alpha) \cdot \beta \cdot tf_{\text{high}} + C_{l_{e\beta}}(qa_{\text{corr}}, M) \cdot \beta \tag{A.151}$$

$$C_{l_{\beta\delta_e}} = (C_{l_{\delta_e\beta}}(|\beta|, \delta_{ei}, \delta_n, \alpha) \cdot \delta_{ei_{\text{eff}}} + C_{l_{\delta_e\beta}}(|\beta|, \delta_{ey}, \delta_n, \alpha) \cdot \delta_{eo_{\text{eff}}}) \cdot \text{sign}(\beta) \tag{A.152}$$

$$C_{l_{\beta\delta_n}} = C_{l_{\delta_n\beta}}(|\beta|, \delta_n, \alpha) \cdot \text{sign}(\beta) \cdot tf_{\text{low}} + C_{l_{\beta M\delta_n}}(\delta_n, 0.5) \cdot \beta \cdot tf_{\text{high}} \tag{A.153}$$

$$C_{l_{\beta\delta_{le}}} = (C_{l_{\delta_{le}\beta}}(\delta_{le}, |\beta|, \delta_{ei}, \alpha) \cdot (1 - C_{l_{dayod}}(0.4)) + C_{l_{\delta_{le}\beta}}(\delta_{le}, |\beta|, \delta_{ey}, \alpha) \cdot C_{l_{dayod}}(0.4)) \cdot \text{sign}(\beta) \cdot tf_{\text{low}} + (C_{l_{\beta\delta_{le}}}(0.5, \delta_{ei}, \alpha) \cdot (1 - C_{l_{dayod}}(0.5)) + C_{l_{\beta\delta_{le}}}(0.5, \delta_{ey}, \alpha) \cdot C_{l_{dayod}}(0.5)) \cdot \beta \cdot \delta_{le}/27.0 \cdot tf_{\text{high}} \tag{A.154}$$

$$C_{l_{\delta_r}} = (C_{l_{\beta\delta_r\alpha}}(|\beta|, \delta_r, \alpha) \cdot tf_{\text{low}} + C_{l_{\delta_r M}}(0.5) \cdot \delta_r \cdot tf_{\text{high}}) \cdot C_{l_{e\delta_r}}(qa_{\text{corr}}, M) \tag{A.155}$$

$$C_{l_{\delta_{ai}}} = ((C_{l_{\delta_a\alpha}}(|\delta_{ai}|, \alpha) \cdot \text{sign}(\delta_{ai}) + (C_{l_{\delta_a l}}(\delta_{ei}, \alpha) - C_{l_{\delta_a l}}(0, \alpha)) \cdot \delta_{ai}) \cdot tf_{\text{low}} + (C_{l_{M\delta_a\alpha}}(0.5, |\delta_{ai}|, \alpha) \cdot \text{sign}(\delta_{ai}) + (C_{l_{\delta_a}}(0.5, \delta_{ei}, \alpha) - C_{l_{\delta_a}}(0.5, 0, \alpha)) \cdot \delta_{ai}) \cdot tf_{\text{high}}) \cdot \delta_{ei_{\text{eff}}} \cdot C_{l_{e\delta_{ai}}}(qa_{\text{corr}}, M) \tag{A.156}$$

$$C_{l_{\delta_{ai}\beta}} = C_{l_{\delta_a\beta\alpha}}(|\alpha|) \cdot (|\delta_{ai}|/30.0) \cdot (|\beta|/20.0) \cdot \delta_{ei_{\text{eff}}} \cdot tf_{\text{low}} \tag{A.157}$$

$$C_{l_{\delta_{ay}}} = ((C_{l_{\delta_a\alpha}}(|\delta_{ay}|, \alpha) \cdot \text{sign}(\delta_{ay}) + (C_{l_{\delta_a l}}(\delta_{ey}, \alpha) - C_{l_{\delta_a l}}(0, \alpha)) \cdot \delta_{ay}) \cdot tf_{\text{low}} + (C_{l_{M\delta_a\alpha}}(0.5, |\delta_{ay}|, \alpha) \cdot \text{sign}(\delta_{ay}) + (C_{l_{\delta_a}}(0.5, \delta_{ey}, \alpha) - C_{l_{\delta_a}}(0.5, 0, \alpha)) \cdot \delta_{ay}) \cdot tf_{\text{high}}) \cdot \delta_{eo_{\text{eff}}} \cdot C_{l_{e\delta_{ay}}}(qa_{\text{corr}}, M) \tag{A.158}$$

$$C_{l_{\delta_{ay}\beta}} = C_{l_{\delta_a\beta\alpha}}(|\alpha|) \cdot (|\delta_{ay|}/30.0) \cdot (|\beta|/20.0) \cdot \delta_{eo_{\text{eff}}} \cdot tf_{\text{low}} \tag{A.159}$$

$$C_{l_{\delta_{na}}} = (C_{l_{\delta_{na}\alpha}}(\delta_{ne}, \alpha) \cdot tf_{\text{low}} + C_{l_{\delta_{na}\alpha M}}(\alpha, 0.5) \cdot tf_{\text{high}}) \cdot \delta_{na} \tag{A.160}$$

$$C_{l_{\dot\beta}} = (C_{l_{\dot\beta l}}(\alpha) \cdot tf_{\text{low}} + C_{l_{\dot\beta h}}(\alpha, 0.5) \cdot tf_{\text{high}}) \cdot \dot\beta \tag{A.161}$$

$$C_{l_p} = (C_{l_{p\alpha}}(\delta_n, \alpha) \cdot tf_{\text{low}} + C_{l_{p\alpha M}}(\alpha, 0.5) \cdot tf_{\text{high}}) \cdot p_c \cdot C_{l_{ep}}(qa_{\text{corr}}, M) \tag{A.162}$$

$$C_{l_{p\beta}} = C_{l_{p\beta\alpha}}(|\beta|, \alpha) \cdot p_c \cdot tf_{\text{low}} \tag{A.163}$$

$$C_{l_r} = (C_{l_{r\alpha}}(\delta_n, \alpha) \cdot tf_{\text{low}} + C_{l_{r\alpha M}}(\alpha, 0.5) \cdot tf_{\text{high}}) \cdot r_c \tag{A.164}$$

$$C_{l_{r\beta}} = C_{l_{r\beta\alpha}}(|\beta|, \alpha) \cdot r_c \cdot tf_{\text{low}} \tag{A.165}$$

$$C_{l_{r\delta_e}} = C_{l_{r\delta_e M}}(M) \cdot C_{l_{rk\alpha}}(|\alpha|) \cdot (\delta_{ei_{\text{eff}}} \cdot \delta_{ei}/30.0 + \delta_{eo_{\text{eff}}} \cdot \delta_{ey}/30.0) \cdot r_c \tag{A.166}$$

$0.5 \leq \text{Mach} \leq 1.4$:

$$C_{l_{\text{basic}}} = 0 \tag{A.167}$$

$$C_{l_\beta} = (C_{l_{\beta M\alpha}}(M, \alpha) + C_{l_{e\beta}}(qa_{\text{corr}}, M)) \cdot \beta \tag{A.168}$$

$$C_{l_{\beta\delta_e}} = (C_{l_{\delta_e\beta}}(|\beta|, \delta_{ei}, \delta_n, \alpha) \cdot \delta_{ei_{\text{eff}}} + C_{l_{\delta_e\beta}}(|\beta|, \delta_{ey}, \delta_n, \alpha) \cdot \delta_{eo_{\text{eff}}}) \cdot C_{l_{bkM}}(M) \cdot \text{sign}(\beta) \tag{A.169}$$

$$C_{l_{\beta\delta_n}} = C_{l_{\beta M\delta_n}}(\delta_n, M) \cdot \beta \tag{A.170}$$

$$C_{l_{\beta\delta_{le}}} = (C_{l_{\beta\delta_{le}}}(M, \delta_{ei}, \alpha) \cdot \delta_{ei_{\text{eff}}} + C_{l_{\beta\delta_{le}}}(M, \delta_{ey}, \alpha) \cdot \delta_{eo_{\text{eff}}}) \cdot \beta \cdot \delta_{le}/27.0 \tag{A.171}$$

$$C_{l_r} = C_{l_{\delta_r M}}(M) \cdot \delta_r \cdot C_{l_{e\delta_r}}(qa_{\text{corr}}, M) \tag{A.172}$$

$$C_{l_{\delta_{ai}}} = (C_{l_{M\delta_a\alpha}}(M, |\delta_{ai}|, \alpha) \cdot \text{sign}(\delta_{ai}) + (C_{l_{M\delta_a}}(M, \delta_{ei}, \alpha) - C_{l_{M\delta_a}}(M, 0, \alpha)) \cdot \delta_{ai}) \cdot \delta_{ei_{\text{eff}}} \cdot C_{l_{e\delta_{ai}}}(qa_{\text{corr}}, M) \tag{A.173}$$

$$C_{l_{\delta_{ai}\beta}} = 0 \tag{A.174}$$

$$
\begin{aligned}
C_{l_{\delta_{ay}}} &= (C_{l_{M\delta_a\alpha}}(M, |\delta_{ay}|, \alpha) \cdot \mathrm{sign}(\delta_{ay}) + (C_{l_{M\delta_a}}(M, \delta_{ey}, \alpha) - \\
&\quad C_{l_{M\delta_a}}(M, 0, \alpha)) \cdot \delta_{ay}) \cdot \delta_{eo_{\mathrm{eff}}} \cdot C_{l_{e\delta_{ay}}}(qa_{\mathrm{corr}}, M) && \text{(A.175)} \\
C_{l_{\delta_{ay}\beta}} &= 0 && \text{(A.176)} \\
C_{l_{\delta_{na}}} &= C_{l_{\delta_{na}\alpha M}}(\alpha, M) \cdot \delta_{na} && \text{(A.177)} \\
C_{l_{\dot\beta}} &= C_{l_{\dot\beta h}}(\alpha, M) \cdot \dot\beta && \text{(A.178)} \\
C_{l_p} &= C_{l_{p\alpha M}}(\alpha, M) \cdot p_c \cdot C_{l_{ep}}(qa_{\mathrm{corr}}, M) && \text{(A.179)} \\
C_{l_{p\beta}} &= 0 && \text{(A.180)} \\
C_{l_r} &= C_{l_{r\alpha M}}(\alpha, M) \cdot r_c && \text{(A.181)} \\
C_{l_{r\beta}} &= 0 && \text{(A.182)} \\
C_{l_{r\delta_e}} &= C_{l_{r\delta_e M}}(M) \cdot C_{l_{rka}}(|\alpha|) \cdot (\delta_{ei_{\mathrm{eff}}} \cdot \delta_{ei}/30.0 + \delta_{eo_{\mathrm{eff}}} \cdot \delta_{ey}/30.0) \cdot \\
&\quad r_c && \text{(A.183)} \\
C_{l_{\mathrm{tot}}} &= C_{l_{\mathrm{basic}}} + C_{l_\beta} + C_{l_{\beta\delta_e}} + C_{l_{\beta\delta_n}} + C_{l_{\beta\delta_{le}}} + C_{l_r} + C_{l_{\delta_{ai}}} + \\
&\quad C_{l_{\delta_{ai}\beta}} + C_{l_{\delta_{ay}}} + C_{l_{\delta_{ay}\beta}} + C_{l_{\delta_{na}}} + C_{l_{\dot\beta}} + C_{l_p} + C_{l_{p\beta}} + \\
&\quad C_{l_r} + C_{l_{r\beta}} + C_{l_{r\delta_e}} && \text{(A.184)}
\end{aligned}
$$

Pitching moment coefficient Mach ≤ 0.4:

$$
\begin{aligned}
C_{m_{\mathrm{basic}}} &= C_{m0}(M) + C_{m_{e0}}(qa_{\mathrm{corr}}, M) && \text{(A.185)} \\
C_{m_\alpha} &= C_{m_{\delta_e\alpha}}(0, \alpha) + C_{m_{e\alpha}}(qa_{\mathrm{corr}}, M) \cdot \alpha && \text{(A.186)} \\
C_{m_{\delta_{ei}}} &= (C_{m_{\delta_e\alpha}}(\delta_{ei}, \alpha) - C_{m_{\delta_e\alpha}}(0, \alpha)) \cdot \delta_{ei_{\mathrm{eff}}} \cdot C_{m_{e\delta_{ei}}}(qa_{\mathrm{corr}}, M) && \text{(A.187)} \\
C_{m_{\delta_{ey}}} &= (C_{m_{\delta_e\alpha}}(\delta_{ey}, \alpha) - C_{m_{\delta_e\alpha}}(0, \alpha)) \cdot \delta_{eo_{\mathrm{eff}}} \cdot C_{m_{e\delta_{ey}}}(qa_{\mathrm{corr}}, M) && \text{(A.188)} \\
C_{m_{\delta_e\delta_n}} &= C_{m_{\delta_n\delta_e}}(\delta_n, \delta_e, \alpha) && \text{(A.189)} \\
C_{m_{\delta_n}} &= C_{m_{\delta_n\alpha}}(\delta_n, \alpha) \cdot C_{m_{e\delta_n}}(qa_{\mathrm{corr}}, M) && \text{(A.190)} \\
C_{m_{\delta_{le}}} &= (C_{m_{\delta_{le}\alpha}}(\alpha) + C_{m_{\delta_{le}\delta_e\alpha}}(\delta_e, \alpha) + C_{m_{\delta_{le}\delta_n\alpha}}(\delta_n, \alpha)) \cdot \delta_{le}/27.0 + \\
&\quad (C_{m_{e\delta_{le}i}}(qa_{\mathrm{corr}}, M) + C_{m_{e\delta_{le}y}}(qa_{\mathrm{corr}}, M)) \cdot \delta_{le} && \text{(A.191)} \\
C_{m_{cai}} &= C_{m_{cai}}(cai, \alpha) + C_{m_{cai\delta_n}}(\delta_n, cai, \alpha) && \text{(A.192)} \\
C_{m_\beta} &= C_{m_\beta}(|\beta|, \delta_n, \alpha) && \text{(A.193)} \\
C_{m_{\delta_a}} &= C_{m_{\delta_a\alpha}}(|\delta_{ai}|, \alpha) \cdot \delta_{ei_{\mathrm{eff}}} + C_{m_{\delta_a\alpha}}(|\delta_{ay}|, \alpha) \cdot \delta_{eo_{\mathrm{eff}}} && \text{(A.194)} \\
C_{m_{\dot\alpha}} &= C_{m_{\dot\alpha\alpha M}}(|\alpha|, M) \cdot \dot\alpha && \text{(A.195)} \\
C_{m_q} &= (C_{m_{q\alpha}}(\alpha) + C_{m_{q\delta_n\alpha}}(\delta_n, \alpha)) \cdot q_c \cdot C_{m_{eq}}(qa_{\mathrm{corr}}, M) && \text{(A.196)} \\
C_{m_{n_z}} &= C_{m_{en_z}}(qa_{\mathrm{corr}}, M) \cdot (n_z - 1) && \text{(A.197)} \\
C_{m_{\dot q}} &= C_{m_{e\dot q}}(qa_{\mathrm{corr}}, M) \cdot \dot q && \text{(A.198)} \\
C_m^{\mathrm{high}} &= C_{m_{\alpha 0}}^{\mathrm{high}}(\alpha) + C_{m_{\alpha\delta_n}}^{\mathrm{high}}(\delta_n, \alpha) + C_{m_{\alpha\delta_e}}^{\mathrm{high}}(\delta_e, \alpha) && \text{(A.199)}
\end{aligned}
$$

$0.4 <$ Mach < 0.5:

$$
\begin{aligned}
C_{m_{\mathrm{basic}}} &= C_{m0}(M) + C_{m_{e0}}(qa_{\mathrm{corr}}, M) && \text{(A.200)} \\
C_{m_\alpha} &= C_{m_{\delta_e\alpha}}(0, \alpha) \cdot tf_{\mathrm{low}} + C_{m_{M\delta_e\alpha}}(0.5, 0, \alpha) \cdot tf_{\mathrm{high}} + \\
&\quad C_{m_{e\alpha}}(qa_{\mathrm{corr}}, M) \cdot \alpha && \text{(A.201)} \\
C_{m_{\delta_{ei}}} &= ((C_{m_{\delta_e\alpha}}(\delta_{ei}, \alpha) - C_{m_{\delta_e\alpha}}(0, \alpha)) \cdot tf_{\mathrm{low}} + (C_{m_{M\delta_e\alpha}}(0.5, \delta_{ei}, \alpha) - \\
&\quad C_{m_{M\delta_e\alpha}}(0.5, 0, \alpha)) \cdot tf_{\mathrm{high}}) \cdot \delta_{ei_{\mathrm{eff}}} \cdot C_{m_{e\delta_{ei}}}(qa_{\mathrm{corr}}, M) && \text{(A.202)} \\
C_{m_{\delta_{ey}}} &= ((C_{m_{\delta_e\alpha}}(\delta_{ey}, \alpha) - C_{m_{\delta_e\alpha}}(0, \alpha)) \cdot tf_{\mathrm{low}} + (C_{m_{M\delta_e\alpha}}(0.5, \delta_{ey}, \alpha) - \\
&\quad C_{m_{M\delta_e\alpha}}(0.5, 0, \alpha)) \cdot tf_{\mathrm{high}}) \cdot \delta_{eo_{\mathrm{eff}}} \cdot C_{m_{e\delta_{ey}}}(qa_{\mathrm{corr}}, M) && \text{(A.203)} \\
C_{m_{\delta_e\delta_n}} &= C_{m_{\delta_n\delta_e}}(\delta_n, \delta_e, \alpha) \cdot tf_{\mathrm{low}} && \text{(A.204)} \\
C_{m_{\delta_n}} &= (C_{m_{\delta_n\alpha}}(\delta_n, \alpha) \cdot tf_{\mathrm{low}} + C_{m_{M\delta_n\alpha}}(0.5, \delta_n, \alpha) \cdot tf_{\mathrm{high}}) \cdot \\
&\quad C_{m_{e\delta_n}}(qa_{\mathrm{corr}}, M) && \text{(A.205)} \\
C_{m_{\delta_{le}}} &= (C_{m_{\delta_{le}\alpha l}}(\alpha) + C_{m_{\delta_{le}\delta_e\alpha}}(\delta_e, \alpha) + C_{m_{\delta_{le}\delta_n\alpha}}(\delta_n, \alpha)) \cdot \delta_{le}/27.0 \cdot tf_{\mathrm{low}} +
\end{aligned}
$$

$$
\begin{aligned}
& C_{m_{M\delta_{le}\alpha}}(0.5, \delta_{le}, \alpha) \cdot tf_{\text{high}} + (C_{m_{e\delta_{le}i}}(qa_{\text{corr}}, M) + \\
& C_{m_{e\delta_{le}y}}(qa_{\text{corr}}, M)) \cdot \delta_{le} && \text{(A.206)} \\
C_{m_{cai}} &= C_{m_{cai}}(cai, \alpha) + C_{m_{cai\delta_n}}(\delta_n, cai, \alpha) && \text{(A.207)} \\
C_{m_\beta} &= C_{m_\beta}(|\beta|, \delta_n, \alpha) \cdot tf_{\text{low}} && \text{(A.208)} \\
C_{m_{\delta_a}} &= (C_{m_{\delta_a\alpha}}(|\delta_{ai}|, \alpha) \cdot \delta_{ei_{\text{eff}_{\text{low}}}} + C_{m_{\delta_a\alpha}}(|\delta_{ay}|, \alpha) \cdot \delta_{eo_{\text{eff}_{\text{low}}}}) \cdot tf_{\text{low}} && \text{(A.209)} \\
C_{m_{\dot\alpha}} &= C_{m_{\dot\alpha\alpha M}}(|\alpha|, M) \cdot \dot\alpha && \text{(A.210)} \\
C_{m_q} &= ((C_{m_{q\alpha}}(\alpha) + C_{m_{q\delta_n\alpha}}(\delta_n, \alpha)) \cdot tf_{\text{low}} + \\
& C_{m_{q\alpha M}}(\alpha, 0.5) \cdot tf_{\text{high}}) \cdot q_c \cdot C_{m_{eq}}(qa_{\text{corr}}, M) && \text{(A.211)} \\
C_{m_{n_z}} &= C_{m_{en_z}}(qa_{\text{corr}}, M) \cdot (n_z - 1) && \text{(A.212)} \\
C_{m_{\dot q}} &= C_{m_{e\dot q}}(qa_{\text{corr}}, M) \cdot \dot q && \text{(A.213)}
\end{aligned}
$$

$0.5 \leq$ Mach:

$$
\begin{aligned}
C_{m_{\text{basic}}} &= C_{m0}(M) + C_{m_{e0}}(qa_{\text{corr}}, M) && \text{(A.214)} \\
C_{m_\alpha} &= C_{m_{M\delta_e\alpha}}(M, 0, \alpha) + C_{m_{e\alpha}}(qa_{\text{corr}}, M) \cdot \alpha && \text{(A.215)} \\
C_{m_{\delta_{ei}}} &= (C_{m_{M\delta_e\alpha}}(M, \delta_{ei}, \alpha) - C_{m_{M\delta_e\alpha}}(M, 0, \alpha)) \cdot \\
& \delta_{ei_{\text{eff}}} \cdot C_{m_{e\delta_{ei}}}(qa_{\text{corr}}, M) && \text{(A.216)} \\
C_{m_{\delta_{ey}}} &= (C_{m_{M\delta_e\alpha}}(M, \delta_{ey}, \alpha) - C_{m_{M\delta_e\alpha}}(M, 0, \alpha)) \cdot \\
& \delta_{eo_{\text{eff}}} \cdot C_{m_{e\delta_{ey}}}(qa_{\text{corr}}, M) && \text{(A.217)} \\
C_{m_{\delta_e\delta_n}} &= 0 && \text{(A.218)} \\
C_{m_{\delta_n}} &= C_{m_{M\delta_n\alpha}}(M, \delta_n, \alpha) \cdot C_{m_{e\delta_n}}(qa_{\text{corr}}, M) && \text{(A.219)} \\
C_{m_{\delta_{le}}} &= C_{m_{M\delta_{le}\alpha}}(M, \delta_{le}, \alpha) + (C_{m_{e\delta_{le}i}}(qa_{\text{corr}}, M) + \\
& C_{m_{e\delta_{le}y}}(qa_{\text{corr}}, M)) \cdot \delta_{le} && \text{(A.220)} \\
C_{m_{cai}} &= C_{m_{cai}}(cai, \alpha) + C_{m_{cai\delta_n}}(\delta_n, cai, \alpha) && \text{(A.221)} \\
C_{m_\beta} &= 0 && \text{(A.222)} \\
C_{m_{\delta_a}} &= 0 && \text{(A.223)} \\
C_{m_{\dot\alpha}} &= C_{m_{\dot\alpha\alpha M}}(|\alpha|, M) \cdot \dot\alpha && \text{(A.224)} \\
C_{m_q} &= C_{m_{q\alpha M}}(\alpha, M) \cdot q_c \cdot C_{m_{eq}}(qa_{\text{corr}}, M) && \text{(A.225)} \\
C_{m_{n_z}} &= C_{m_{en_z}}(qa_{\text{corr}}, M) \cdot (n_z - 1) && \text{(A.226)} \\
C_{m_{\dot q}} &= C_{m_{e\dot q}}(qa_{\text{corr}}, M) \cdot \dot q && \text{(A.227)} \\
C_{m_{\text{tot}}} &= C_{m_{\text{basic}}} + C_{m_\alpha} + C_{m_{\delta_{ei}}} + C_{m_{\delta_{ey}}} + C_{m_{\delta_e\delta_n}} + C_{m_{\delta_n}} + \\
& C_{m_{\delta_{le}}} + C_{m_{cai}} + C_{m_\beta} + C_{m_{\delta_a}} + C_{m_{\dot\alpha}} + C_{m_q} + C_{m_{n_z}} + \\
& C_{m_{\dot q}} + C_m^{\text{high}} && \text{(A.228)}
\end{aligned}
$$

Yawing moment coefficient Mach ≤ 0.4:

$$
\begin{aligned}
C_{n_{\text{basic}}} &= C_{n0}(|\alpha|) && \text{(A.229)} \\
C_{n_\beta} &= C_{n_{\beta\alpha}}(|\beta|, \alpha) \cdot \text{sign}(\beta) + C_{n_{e\beta}}(qa_{\text{corr}}, M) \cdot \beta && \text{(A.230)} \\
C_{n_{\beta\delta_e}} &= (C_{n_{\delta_e\beta}}(|\beta|, \delta_{ei}, \alpha) \cdot \delta_{ei_{\text{eff}}} + C_{n_{deb}}(|\beta|, \delta_{ey}, \alpha) \cdot \delta_{eo_{\text{eff}}}) \cdot \\
& \text{sign}(\beta) && \text{(A.231)} \\
C_{n_{\beta\delta_n}} &= C_{n_{\delta_n\beta}}(|\beta|, \delta_n, \alpha) \cdot \text{sign}(\beta) && \text{(A.232)} \\
C_{n_{\beta\delta_{le}}} &= (C_{n_{\delta_{le}\beta}}(\delta_{le}, |\beta|, \delta_{ei}, \alpha) \cdot \delta_{ei_{\text{eff}}} + C_{n_{\delta_{le}\beta}}(\delta_{le}, |\beta|, \delta_{ey}, \alpha) \cdot \delta_{eo_{\text{eff}}}) \cdot \\
& \text{sign}(\beta) && \text{(A.233)} \\
C_{n_{cai}} &= C_{n_{\beta cai}}(cai, \alpha) \cdot \beta && \text{(A.234)} \\
C_{n_{\delta_r}} &= C_{n_{\beta\delta_r\alpha}}(\beta, \delta_r, \alpha) \cdot C_{n_{e\delta_r}}(qa_{\text{corr}}, M) && \text{(A.235)} \\
C_{n_{\delta_{ai}}} &= (C_{n_{\delta_a\alpha}}(|\delta_{ai}|, \alpha) \cdot \text{sign}(\delta_{ai}) + (C_{n_{\delta_a l}}(\delta_{ei}, \alpha) - \\
& C_{n_{\delta_a l}}(0, \alpha)) \cdot \delta_{ai}) \cdot \delta_{ei_{\text{eff}}} \cdot C_{n_{e\delta_{ai}}}(qa_{\text{corr}}, M) && \text{(A.236)}
\end{aligned}
$$

$$
\begin{aligned}
C_{n_{\delta_{ai}\beta}} &= C_{n_{\delta_a\beta\alpha}}(|\alpha|)\cdot(|\delta_{ai}|/30.0)\cdot(|\beta|/20.0)\cdot\delta_{ei_{\text{eff}}} && \text{(A.237)}\\
C_{n_{\delta_{ay}}} &= (C_{n_{\delta_a\alpha}}(|\delta_{ay}|,\alpha)\cdot\text{sign}(\delta_{ay})+(C_{n_{\delta_a l}}(\delta_{ey},\alpha)-\\
&\quad C_{n_{\delta_a l}}(0,\alpha))\cdot\delta_{ay})\cdot\delta_{eo_{\text{eff}}}+C_{n_{e\delta_{ay}}}(qa_{\text{corr}},M)\cdot\delta_{ay} && \text{(A.238)}\\
C_{n_{\delta_{ay}\beta}} &= C_{n_{\delta_a\beta\alpha}}(|\alpha|)\cdot(|\delta_{ay}|/30.0)\cdot(|\beta|/20.0)\cdot\delta_{eo_{\text{eff}}} && \text{(A.239)}\\
C_{n_{\delta_{na}}} &= C_{n_{\delta_{na}\alpha}}(\delta_{ne},\alpha)\cdot\delta_{na} && \text{(A.240)}\\
C_{n_{\dot\beta}} &= C_{n_{\dot\beta l}}(\alpha)\cdot\dot\beta && \text{(A.241)}\\
C_{n_p} &= (C_{n_{p\alpha l}}(\delta_n,\alpha)+C_{n_{ep}}(qa_{\text{corr}},M))\cdot p_c && \text{(A.242)}\\
C_{n_{p\beta}} &= C_{n_{p\beta\alpha}}(|\beta|,\alpha)\cdot p_c && \text{(A.243)}\\
C_{n_r} &= C_{n_{r\alpha l}}(\delta_n,\alpha)\cdot r_c\cdot C_{n_{er}}(qa_{\text{corr}},M) && \text{(A.244)}\\
C_{n_{r\beta}} &= C_{n_{r\beta\alpha}}(|\beta|,\alpha)\cdot r_c && \text{(A.245)}
\end{aligned}
$$

$0.4 <$ Mach < 0.5:

$$
\begin{aligned}
C_{n_{\text{basic}}} &= C_{n0}(|\alpha|)\cdot tf_{\text{low}} && \text{(A.246)}\\
C_{n_\beta} &= C_{n_{\beta\alpha}}(|\beta|,\alpha)\cdot\text{sign}(\beta)\cdot tf_{\text{low}}+C_{n_{M\alpha\beta}}(0.5,\alpha,|\beta|)\cdot\text{sign}(\beta)\cdot tf_{\text{high}}+\\
&\quad C_{n_{e\beta}}(qa_{\text{corr}},M)\cdot\beta && \text{(A.247)}\\
C_{n_{\beta\delta_e}} &= (C_{n_{\delta_e\beta}}(|\beta|,\delta_{ei},\alpha)\cdot\delta_{ei_{\text{eff}}}+C_{n_{\delta_e\beta}}(|\beta|,\delta_{ey},\alpha)\cdot\delta_{eo_{\text{eff}}})\cdot\text{sign}(\beta) && \text{(A.248)}\\
C_{n_{\beta\delta_n}} &= C_{n_{\delta_n\beta}}(|\beta|,\delta_n,\alpha)\cdot\text{sign}(\beta) && \text{(A.249)}\\
C_{n_{\beta\delta_{le}}} &= (C_{n_{\delta_{le}\beta}}(\delta_{le},|\beta|,\delta_{ei},\alpha)\cdot(1.0-C_{n_{dayod}}(0.4))+C_{n_{\delta_{le}\beta}}(\delta_{le},|\beta|,\delta_{ey},\alpha)\cdot\\
&\quad C_{n_{dayod}}(0.4))\cdot\text{sign}(\beta)\cdot tf_{\text{low}}+(C_{n_{\beta\delta_{le}}}(0.5,\delta_{ei},\alpha)\cdot\\
&\quad (1.0-C_{n_{dayod}}(0.5))+C_{n_{\beta\delta_{le}}}(0.5,\delta_{ey},\alpha)\cdot C_{n_{dayod}}(0.5))\cdot\\
&\quad \beta\cdot\delta_{le}/27.0\cdot tf_{\text{high}} && \text{(A.250)}\\
C_{n_{cai}} &= C_{n_{\beta cai}}(cai,\alpha)\cdot\beta && \text{(A.251)}\\
C_{n_{\delta_r}} &= (C_{n_{\beta\delta_r\alpha}}(\beta,\delta_r,\alpha)\cdot tf_{\text{low}}+C_{n_{\delta_r\alpha M}}(\alpha,0.5)\cdot\delta_r\cdot tf_{\text{high}})\cdot\\
&\quad C_{n_{e\delta_r}}(qa_{\text{corr}},M) && \text{(A.252)}\\
C_{n_{\delta_{ai}}} &= ((C_{n_{\delta_a\alpha}}(|\delta_{ai}|,\alpha)\cdot\text{sign}(\delta_{ai})+(C_{n_{\delta_a l}}(\delta_{ei},\alpha)-C_{n_{\delta_a l}}(0,\alpha))\cdot\delta_{ai})\cdot\\
&\quad tf_{\text{low}}+(C_{n_{M\delta_a\alpha}}(0.5,|\delta_{ai}|,\alpha)\cdot\text{sign}(\delta_{ai})+(C_{n_{\delta_a}}(0.5,\delta_{ei},\alpha)-\\
&\quad C_{n_{\delta_a}}(0.5,0,\alpha))\cdot\delta_{ai})\cdot tf_{\text{high}})\cdot\delta_{ei_{\text{eff}}}\cdot C_{n_{e\delta_{ai}}}(qa_{\text{corr}},M) && \text{(A.253)}\\
C_{n_{\delta_{ai}\beta}} &= C_{n_{\delta_a\beta\alpha}}(|\alpha|)\cdot(|\delta_{ai}|/30.0)\cdot(|\beta|/20.0)\cdot\delta_{ei_{\text{eff}}}\cdot tf_{\text{low}} && \text{(A.254)}\\
C_{n_{\delta_{ay}}} &= ((C_{n_{\delta_a\alpha}}(|\delta_{ay}|,\alpha)\cdot\text{sign}(\delta_{ay})+(C_{n_{\delta_a l}}(\delta_{ey},\alpha)-C_{n_{\delta_a l}}(0,\alpha))\cdot\delta_{ay})\cdot\\
&\quad tf_{\text{low}}+(C_{n_{M\delta_a\alpha}}(0.5,|\delta_{ay}|,\alpha)\cdot\text{sign}(\delta_{ay})+(C_{n_{\delta_a}}(0.5,\delta_{ey},\alpha)-\\
&\quad C_{n_{\delta_a}}(0.5,0,\alpha))\cdot\delta_{ay})\cdot tf_{\text{high}})\cdot\delta_{eo_{\text{eff}}}+C_{n_{e\delta_{ay}}}(qa_{\text{corr}},M)\cdot\delta_{ay} && \text{(A.255)}\\
C_{n_{\delta_{ay}\beta}} &= C_{n_{\delta_a\beta\alpha}}(|\alpha|)\cdot(|\delta_{ay}|/30.0)\cdot(|\beta|/20.0)\cdot\delta_{eo_{\text{eff}}}\cdot tf_{\text{low}} && \text{(A.256)}\\
C_{n_{\delta_{na}}} &= (C_{n_{\delta_{na}\alpha}}(\delta_{ne},\alpha)\cdot tf_{\text{low}}+C_{n_{\delta_{na}\alpha M}}(\alpha,0.5)\cdot tf_{\text{high}})\cdot\delta_{na} && \text{(A.257)}\\
C_{n_{\dot\beta}} &= (C_{n_{\dot\beta l}}(\alpha)\cdot tf_{\text{low}}+C_{n_{\dot\beta h}}(\alpha,0.5)\cdot tf_{\text{high}})\cdot\dot\beta && \text{(A.258)}\\
C_{n_p} &= (C_{n_{p\alpha l}}(\delta_n,\alpha)\cdot tf_{\text{low}}+C_{n_{p\alpha M}}(\alpha,0.5)\cdot tf_{\text{high}}+\\
&\quad C_{n_{ep}}(qa_{\text{corr}},M))\cdot p_c && \text{(A.259)}\\
C_{n_{p\beta}} &= C_{n_{p\beta\alpha}}(|\beta|,\alpha)\cdot p_c\cdot tf_{\text{low}} && \text{(A.260)}\\
C_{n_r} &= (C_{n_{r\alpha l}}(\delta_n,\alpha)\cdot tf_{\text{low}}+C_{n_{r\alpha M}}(\delta_n,\alpha,0.5)\cdot tf_{\text{high}})\cdot\\
&\quad r_c\cdot C_{n_{er}}(qa_{\text{corr}},M) && \text{(A.261)}\\
C_{n_{r\beta}} &= C_{n_{r\beta\alpha}}(|\beta|,\alpha)\cdot r_c\cdot tf_{\text{low}} && \text{(A.262)}
\end{aligned}
$$

$0.5 \leq$ Mach ≤ 1.4:

$$
\begin{aligned}
C_{n_{\text{basic}}} &= 0 && \text{(A.263)}\\
C_{n_\beta} &= C_{n_{M\alpha\beta}}(M,\alpha,|\beta|)\cdot\text{sign}(\beta)+C_{n_{e\beta}}(qa_{\text{corr}},M)\cdot\beta && \text{(A.264)}\\
C_{n_{\beta\delta_e}} &= (C_{n_{\delta_e\beta}}(|\beta|,\delta_{ei},\alpha)\cdot\delta_{ei_{\text{eff}}}+C_{n_{\delta_e\beta}}(|\beta|,\delta_{ey},\alpha)\cdot\delta_{eo_{\text{eff}}})\cdot
\end{aligned}
$$

$$
\begin{aligned}
& C_{n_{bkM}}(M) \cdot \mathrm{sign}(\beta) && \text{(A.265)}\\
C_{n_{\beta\delta_n}} &= C_{n_{\delta_n\beta}}(|\beta|, \delta_n, \alpha) \cdot \mathrm{sign}(\beta) && \text{(A.266)}\\
C_{n_{\beta\delta_{le}}} &= (C_{n_{\beta\delta_{le}}}(M, \delta_{ei}, \alpha) \cdot \delta_{ei_{\mathrm{eff}}} + C_{n_{\beta\delta_{le}}}(M, \delta_{ey}, \alpha) \cdot \delta_{eo_{\mathrm{eff}}}) \cdot \beta \cdot \\
& \delta_{le}/27.0 && \text{(A.267)}\\
C_{n_{cai}} &= C_{n_{\beta cai}}(cai, \alpha) \cdot \beta && \text{(A.268)}\\
C_{n_{\delta_r}} &= C_{n_{\delta_r\alpha M}}(\alpha, M) \cdot \delta_r \cdot C_{n_{e\delta_r}}(qa_{\mathrm{corr}}, M) && \text{(A.269)}\\
C_{n_{\delta_{ai}}} &= (C_{n_{M\delta_a\alpha}}(M, |\delta_{ai}|, \alpha) \cdot \mathrm{sign}(\delta_{ai}) + (C_{n_{\delta_a}}(M, \delta_{ei}, \alpha) - \\
& C_{n_{\delta_a}}(M, 0, \alpha)) \cdot \delta_{ai}) \cdot \delta_{ei_{\mathrm{eff}}} \cdot C_{n_{e\delta_{ai}}}(qa_{\mathrm{corr}}, M) && \text{(A.270)}\\
C_{n_{\delta_{ai}\beta}} &= 0 && \text{(A.271)}\\
C_{n_{\delta_{ay}}} &= (C_{n_{M\delta_a\alpha}}(M, |\delta_{ay}|, \alpha) \cdot \mathrm{sign}(\delta_{ay}) + (C_{n_{\delta_a}}(M, \delta_{ey}, \alpha) - \\
& C_{n_{\delta_a}}(M, 0, \alpha)) \cdot \delta_{ay}) \cdot \delta_{eo_{\mathrm{eff}}} + C_{n_{e\delta_{ay}}}(qa_{\mathrm{corr}}, M) \cdot \delta_{ay} && \text{(A.272)}\\
C_{n_{\delta_{ay}\beta}} &= 0 && \text{(A.273)}\\
C_{n_{\delta_n\alpha}} &= C_{n_{\delta_{na}\alpha M}}(\alpha, M) \cdot \delta_{na} && \text{(A.274)}\\
C_{n_{\dot\beta}} &= C_{n_{\dot\beta}}(\alpha, M) \cdot \dot\beta && \text{(A.275)}\\
C_{n_p} &= (C_{n_{p\alpha M}}(\alpha, M) + C_{n_{ep}}(qa_{\mathrm{corr}}, M)) \cdot p_c && \text{(A.276)}\\
C_{n_{p\beta}} &= 0 && \text{(A.277)}\\
C_{n_r} &= C_{n_{r\alpha M}}(\delta_n, \alpha, M) \cdot r_c \cdot C_{n_{er}}(qa_{\mathrm{corr}}, M) && \text{(A.278)}\\
C_{n_{r\beta}} &= 0 && \text{(A.279)}\\
C_{n_{\mathrm{tot}}} &= C_{n_{\mathrm{basic}}} + C_{n_\beta} + C_{n_{\beta\delta_e}} + C_{n_{\beta\delta_n}} + C_{n_{\beta\delta_{le}}} + C_{n_{cai}} + C_{n_{\delta r}} + \\
& C_{n_{\delta_{ai}}} + C_{n_{\delta_{ai}\beta}} + C_{n_{\delta_{ay}}} + C_{n_{\delta_{ay}\beta}} + C_{n_{\delta_n\alpha}} + C_{n_{\dot\beta}} + C_{n_p} + \\
& C_{n_{p\beta}} + C_{n_r} + C_{n_{r\beta}} && \text{(A.280)}
\end{aligned}
$$

B Uncertainties in the ADMIRE Model

Longitudinal		Lateral	
Uncertainty	Range	Uncertainty	Range
$\delta_{\alpha_{\mathrm{err}}}$	[-2.0,2.0] deg	$\delta_{\alpha_{\mathrm{err}}}$	[-2.0,2.0] deg
$\delta_{M_{\mathrm{err}}}$	[-0.08,0.08][1]	$\delta_{M_{\mathrm{err}}}$	[-0.08,0.08]
$\delta_{x_{cg}}$	[-0.15,0.15]	$\delta_{\beta_{\mathrm{err}}}$	[-2.0,2.0] deg
$\delta_{I_{yy}}$	[-0.05,0.05]	$\delta_{y_{cg}}$	[-0.10,0.10]
$\delta_{C_{m\alpha}}$	[-0.1,0.1]	$\delta_{I_{xx}}$	[-0.20,0.20]
$\delta_{C_{mq}}$	[-0.10,0.10]	$\delta_{I_{zz}}$	[-0.08,0.08]
$\delta_{C_{m\delta_{ey}}}$	[-0.01,0.01]	$\delta_{C_{l\beta}}$	[-0.04,0.04]
$\delta_{C_{m\delta_{ei}}}$	[-0.03,0.03]	$\delta_{C_{lp}}$	[-0.10,0.10]
$\delta_{C_{m\delta_{ne}}}$	[-0.02,0.02]	$\delta_{C_{lr}}$	[-0.10,0.10]
δ_{mass}	[-0.2,0.2]	$\delta_{C_{n\beta}}$	[-0.04,0.04]
		$\delta_{C_{np}}$	[-0.10,0.10]
		$\delta_{C_{nr}}$	[-0.04,0.04]
		$\delta_{C_{n\delta_{na}}}$	[-0.01,0.01]
		$\delta_{C_{n\delta_r}}$	[-0.02,0.02]

Table B.1: Measurement errors and parameter uncertainty in the clearance analysis.

[1]For the ADMIRE clearance analysis $\delta_{M_{\mathrm{err}}}$ ranges by [-0.04,0.04] when nominal Mach number is 0.8 and 1.2. The data measurement error on airspeed V_T, $\delta_{V_T\mathrm{err}}$, is derived in ADMIRE3.4f by simply multiplying $\delta_{M_{\mathrm{err}}}$ with the speed of sound that is computed for the given altitude. Data measurement errors on altitude, $\delta_{\mathrm{alt}_{\mathrm{err}}}$, must be set to zero.

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