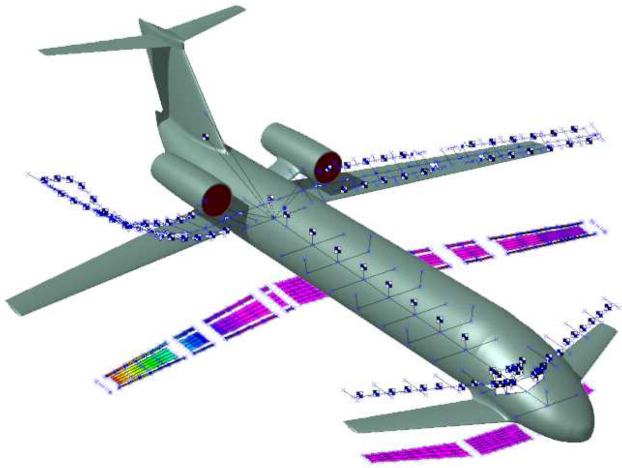
NeoCASS

Next generation Conceptual Aero Structural Sizing



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Appendix A

NeoCASS: add-on

This add-on gives a brief introduction to few enhancements available in NeoCASS concerning the kind of static maneuvers which can be used in GUESS and SMARTCAD analyses.

A.1 Landing maneuver

The typical maneuvers carried out in GUESS during the design phase consider aerodynamic and inertia forces as the only source of loads.
Ground handling operations must be considered as well to encompass every condition which may be severe for few points on the airframe. In this respect, GUESS allows to consider a tail-down landing maneuver. The purpose is twofold:

- include a local stiffening in the attachment zones of fuselage or wing considering the incoming ground reactions of the landing gears;
- assess the overall airframe for the resulting load factor.

Landing impact loads depend on few variables:

- design sink velocity v_s, typically 10 ft/s (see normatives);
- gear and tire characteristics;
- attitude of the aircraft, mass configuration and distribution;
- aerodynamic loads at time of impact.

The way the landing gear absorbs the energy during landing will affect the load factor during the maneuver. This would require to have more details concerning the shock-absorber adopted, which is out of the purpose at this stage of the design. In this respect, the efficiency η_s of the landing gear strut is introduced which considers different details of the shock-absorber, e.g. geometry and non-linearities. Typical values range from 80 to 85 percent. η_s expresses the ratio of the work performed by the strut considered and the ideal case of a strut displaced to X_s with a constant force P_{max}. The adoption of this parameter allows to simply determine the amount of energy the strut can absorb.
A simple energy relation allows to immediately have an estimate of the ground reaction P_{max} and hence of the landing load factor n_{LG}. In the case considered here, the tire is

supposed as rigid, i.e. displacements associated to the deformation of the tire itself, and energy dissipation are neglected.
Thus, considering the vertical axis only, the variation of the kinetic energy of the aircraft will equal the sum of the work performed by gravity, lift and gear strut.
The net work performed by L and W is:

$$\Delta E_{g+a} = (L - W) \cdot X_s \tag{A.1}$$

where X_s is the strut stroke length, W the weight of the aircraft and L the lift force. Exploiting the definition of the efficiency η_s, the contribution of the strut can be easily expressed as:

$$\Delta E_s = \eta_s \, P_{max} \, X_s \tag{A.2}$$

where P_{max} is the maximum value of the vertical load.
Considering the energy balance:

$$\frac{1}{2} \frac{W}{g} v_s^2 = (L - W) \cdot X_s + \eta_s \, P_{max} \, X_s \tag{A.3}$$

the vertical load P_{max} can be determined as:

$$P_{max} = \frac{1}{2} \frac{W}{g} \frac{v_s^2}{\eta_s \, X_s} + \frac{(W - L)}{\eta_s} \tag{A.4}$$

The resulting landing load factor n_{LG} due to the ground reaction will be:

$$n_{LG} = \frac{P_{max}}{W} = \frac{1}{2} \frac{v_s^2}{g\eta_s \, X_s} + \frac{1}{\eta_s} \left(1 - \frac{L}{W} \right) \tag{A.5}$$

The final load factor will be:

$$n_z = n_{LG} + \frac{L}{W} \tag{A.6}$$

A.1.1 Development in NeoCASS

The analysis of the maneuver follows two steps:

1. trim solution for the aircraft immediately before the touchdown, i.e. angle of attack and controls are determined;

2. a second trim solution which combines the solution of the first step and the application of P_{max} when the aircraft hits the ground.

The first solution determines the distribution of the aerodynamic forces along the lifting surfaces so that a certain value of L in Eq.(A.1.1) is given. The aircraft is supposed to descend with a constant vertical velocity. This value of the lift is typically assumed to be 2/3 of the weight. The designer defines this value through the field `URDD3` in the `TRIM` card which gives the vertical inertia force the aerodynamic force must balance. Thus, the solver will determine for a solution with $L = \frac{2}{3}W$ and balanced with respect to moments. The angle of attack and pitch control deflection, e.g. canard, elevator, will be left as unknowns and `URDD3` set to $\frac{2}{3}g = 6.54$ [m/s^2]. In the second step, Eq. will be solved to determine P_{max}.
Extra fields have been added in the `TRIM` card to be define v_s, X_s and η_s:

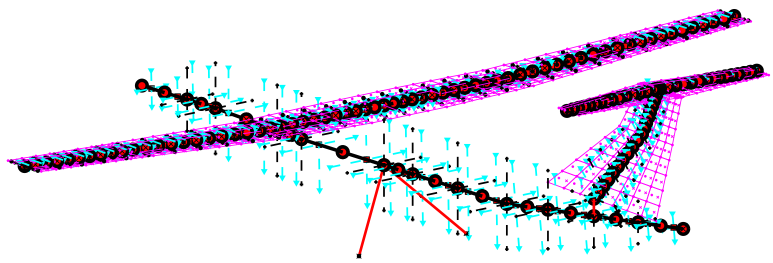


Figure A.1: Rigid elements for landing gears.

- VSINK (units [m/s]) for the sink velocity v_s;
- STROKE (units [m]) for the stroke length X_s;
- LANDGEFF to override the default value 0.8 for η_s.

Successively the ground reaction P_{max} is applied at the attachment points. A model is suitable for a landing analysis when some variables have been defined during the layout definition. The position of the main landing gear is defined in the XML file, or through the Weight and Balance panel of AcBuilder (System CG (optional 3)), as:

- miscellaneous.main_landing_gear_x;
- miscellaneous.main_landing_gear_y;
- miscellaneous.main_landing_gear_z.

These variables give the coordinate of the center of gravity of one leg of the main landing gear. The landing gears is supposed to have two legs only, spanwise symmetric.
To model the landing gear, SMARTCAD will create two dummy nodes at each leg center of gravity and connect them to the airframe through a rigid RBE2 element. Both of them will be labeled as landing gear nodes using a PARAM LANDG in the SMARTCAD file followed by its ID. One more information is required to instruct SMARTCAD where the legs are connected to the airframe. A parameter main_landing_gear_on_fuselage is available in the XML file, or in the Weight and Balance panel of AcBuilder (miscellaneous). Whether set to a null value, the RBE2 will define the nearest node along the wing as master node. Otherwise, fuselage nodes will be considered. If miscellaneous.main_landing_gear_y is set to zero, the landing gear will be defined as single leg and connected to the fuselage only. Fig. A.1 shows a SMARTCAD model of the ATR72. The red lines are the rigid elements connecting the landing gears to the fuselage. No further intervention from the user is required. Once the input data are provided in the XML file, it will be up to GUESS to create a model with landing gear nodes defined (GRID cards), labeled (LANDG parameters) and connected to the airframe (RBE2 cads). Moreover, lumped masses (CONM2

card) corresponding to the weight of each leg will be included in the numeric model.
The second trim solution will be carried out superposing:

- the aerodynamic loads from the the first trim solution modelling the aircraft along a descent at constant velocity;
- P_{max}, equally divided for the number of legs, at the landing gear nodes;

Inertial forces will balance the net vertical load. Rotational inertia forces will balance the moment given by P_{max}. Accelerations are then left as unknowns. Their values will be determined and printed on the screen for the rigid and deformable case.
Below, an example of a landing maneuver is considered.

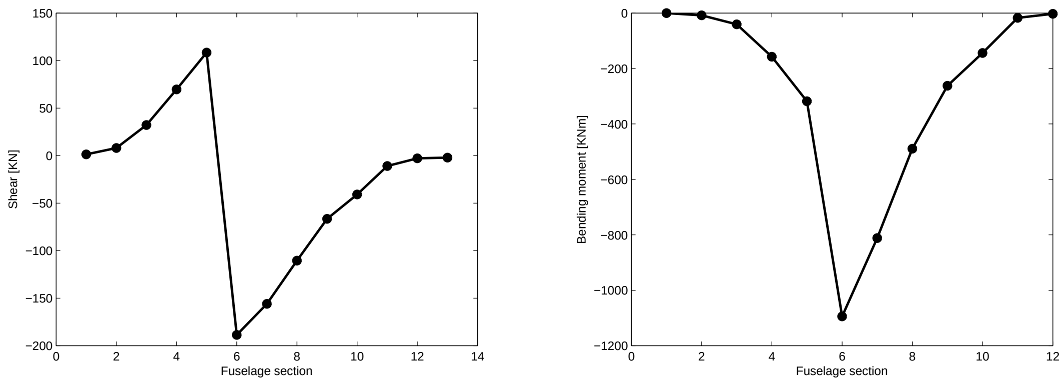
```
TRIM=   1
$ Taildown Landing
TRIM    1       1       0.15    0.0     SIDES   0       ROLL    0
        PITCH   0       YAW     0       URDD2   0       URDD3   6.54
        URDD4   0       URDD5   0       URDD6   0       flap1r  0
        flap2r  0       aileronr0       rudder1 0       CLIMB   0
        BANK    0       HEAD    0       THRUST  0       VSINK   3.0
        STROKE  0.6     LNDGEFF 0.85
$ Landing gear nodes
GRID    9000    0       13.5    2.05    -2.65   0       0       0
GRID    9001    0       13.5    -2.05   -2.65   0       0       0
PARAM   LANDG   9000
PARAM   LANDG   9001
CONM2   110     9000    0       428.747 0       0       0
        0       0       0       0       0       0
CONM2   111     9001    0       428.747 0       0       0
        0       0       0       0       0       0
$ Rigid element for landing gears legs
RBE2    4       1005    123456  9000    9001
```

The definition is similar to a cruise/pull-up maneuver where the angle of attack `ANGLEA` and the elevator `elev1r`are left as unknowns. The lift will have to equal 2/3 of the weight of the model. A sink velocity of 3.0 m/s and a stroke length of 0.6 m will be applied assuming a strut efficiency of 0.85.
Referring to Fig. A.1, the nodes 9000 and 9001 are defined, one for each leg. A mass is also included at these nodes to represent the inertia of each leg. The nodes are labeled as landing gear nodes through `PARAM LANDG`, implying the ground reaction to be applied at these points. Each legs has a mass of 428.747 kilos. This values comes is taken from the Weight and Balance estimate carried out during the layout design and `XML` file creation.
Finally, a rigid element links the landing gear nodes to the fuselage node 1005.
The output on the screen is:

```
- Setting system rhs...
 - Strut efficiency:        0.85 [].
 - Sink velocity:           3 [m/s].
 - Strut stroke:            0.6 [m].
```

```
 - Total vertical reaction: 376118 [N].
- Setting SUPORT matrix...
Warning: 6 SUPORT rigid modes exceed deformation energy tolerance 0.001.done.
Solving rigid aircraft trim condition...
- Setting URDD1 URDD3 and URDD5 as free parameters...done.
 - X acc:      0.393095 [m/s^2].
 - Z acc:      19.7881 [m/s^2].
 - Q-DOT:      -0.383272 [rad/s^2].
done.
Solving deformable aircraft trim condition...
- Setting URDD1 URDD3 and URDD5 as free parameters...done.
 - X acc:      0.379387 [m/s^2].
 - Z acc:      20.0258 [m/s^2].
 - Q-DOT:      -0.374927 [rad/s^2].
done.
```

The load factor n_z for the rigid case is $\frac{19.7881}{9.81} = 2.0$. A pitching down acceleration results from applying the ground reaction to a point farther the center of gravity.
Fig. A.2 shows the internal shear force and bending moment along the fuselage bar elements. Fig. A.3 shows the final deformed shape at the touchdown. The wing bends



(a) Shear

(b) Bending

Figure A.2: Internal forces along fuselage bar elements.

upward because the local lift distribution prevails over the inertial one.

A.2 Steady vertical gust

The final analysis of the airframe must consider both the maneuver envelope encompassing all the critical flight points and the gust envelope, i.e. the envelope of velocities and load factors for flight in moving air.
When encountering a gust, the aircraft undergoes a variation in aerodynamic loads due to a change of the angle of attack. For sake of simplicity, the gust has been assumed to be spanwise uniform, featuring a sharp edge velocity v_g along the vertical axis only,

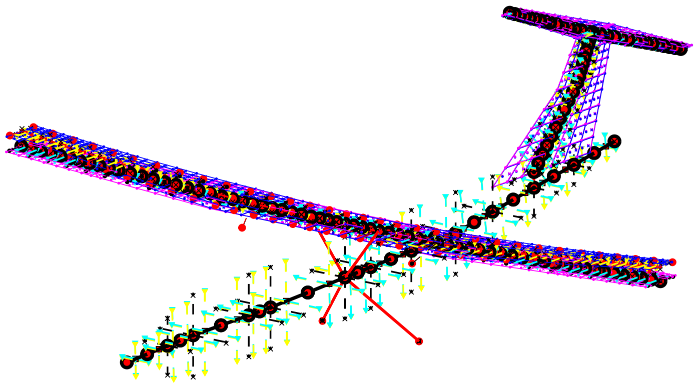


Figure A.3: Final deformed shape at touchdown.

perpendicular to the flight path. When the aircraft cruises at velocity V_∞, the variation of the angle of attack is:

$$\Delta\alpha_g = \arctan\frac{v_g}{V_\infty} \approx \frac{v_g}{V_\infty}. \tag{A.7}$$

supping $v_g << V_\infty$.
The variation of lift can be easily expressed as:

$$\Delta L = \frac{1}{2}\rho_\infty V_\infty^2 S C_{L_\alpha}\Delta\alpha \tag{A.8}$$

where C_{L_α} is the lift curve slope, ρ_∞ the flight density and S the reference wing surface. Including Eq. (A.7) in Eq. (A.8), the variation of lift reads:

$$\Delta L = \frac{1}{2}\rho_\infty V_\infty^2 S C_{L_\alpha}\frac{v_g}{V_\infty} = \frac{1}{2}\rho_\infty S C_{L_\alpha} V_\infty v_g \tag{A.9}$$

resulting in a change of load factor Δn_z:

$$\Delta n_z = \frac{\Delta L}{W} = \frac{1}{2}\rho_\infty \frac{S}{W} C_{L_\alpha} V_\infty v_g \tag{A.10}$$

where W is the weight of the aircraft. The dependence of n_z with wing loading $\frac{W}{S}$ is highlighted. Because of the perturbation, the aircraft will start moving vertically (following the gust) and pitching nose-down (if stable), resulting in a reduction of the angle of attack. The process is similar when the aircraft exits the gust. In the intermediate stage, the angle of attack will depend on the the gust velocity profile and of the perturbed motion itself.
The following simplifications will be applied for the analysis:

- only static loads will be considered, i.e. structural dynamic response neglected;

- ΔL will still act at the aerodynamic center of the unperturbed condition;
- only the plunge motion will be considered;
- the aircraft is supposed to encounter the gust at $n_z = 1$;
- the aircraft senses the gust instantaneously;

Normatives are also adopted:

- a $1 - \cos$ gust profile is assumed;
- it results in a smooth variation of lift, hence of n_z, which sounds more realistic than a sharp edge gust;
- a gust attenuation factor K_g is defined to consider the lag of ΔL due to $\Delta\alpha$ and the perturbed motion of the aircraft.

K_g helps in simplifying the analysis: n_z will reach its maximum value with a certain delay with respect to when the gust hits the aircraft and starts plunging. K_g is then is an attempt to account for gust gradient and airplane response with a single parameter. Also no transient simulation has to be carried out.
Following the normatives, the maximum value of n_z will be:

$$n_z = 1 + \frac{1}{2}\rho_0 \frac{S}{W} C_{L_\alpha} V_{\infty_{EAS}}\, v_{eg_{EAS}} K_g \tag{A.11}$$

where ρ_0 is the sea level air density. The gust alleviation factor depends on wing loading W/S, lift curve slope C_{L_α}, air density ρ_∞ and a characteristic length c, i.e. wing mean aerodynamic chord.
K_g is given as function of a mass parameter μ_g:

$$K_g = \frac{0.88\,\mu_g}{5.3 + \mu_g} \tag{A.12}$$

defined as:

$$\mu_g = \frac{2W/S}{\rho_\infty\, g\, c\, C_{L_\alpha}} \tag{A.13}$$

$v_{eg_{EAS}}$ is the effective equivalent gust velocity:

$$v_{eg_{EAS}} = v_g \sqrt{\frac{\rho_\infty}{\rho_0}} \tag{A.14}$$

The values of $v_{eg_{EAS}}$ are prescribed by normatives at cruise V_c and dive speed V_d. For example, considering FAR23 and V_c as design point, the gust intensity is:

- $v_{eg_{EAS}} = 50\,\text{fps}$ for $0 \leq z \leq 20000\,\text{ft}$;
- $v_{eg_{EAS}} = 25\,\text{fps}$ for $z > 50000\,\text{ft}$;

with a linear interpolation for intermediate values of z.
Considering FAR25 and the same design point, the gust intensity is:

- $v_{eg_{EAS}} = 56\,\text{fps}$ for $z = 0\,\text{ft}$;
- $v_{eg_{EAS}} = 44\,\text{fps}$ for $z = 15000\,\text{ft}$;
- $v_{eg_{EAS}} = 26\,\text{fps}$ for $z = 50000\,\text{ft}$;

again with a linear interpolation for intermediate values of z.

A.2.1 Development in SMARTCAD

In order to solve for n_z in Eq. (A.11), the only parameter to be defined is the gust intensity $v_{eg_{EAS}}$. This is provided through the field `VGUST` in the `TRIM` card. The solver always applies the absolute value, i.e. the gust is supposed to be vertical ascending. The reference values are those given in the `AEROS` card, the density is the one defined in the `TRIM` card and C_{L_α} is taken from the internal Vortex Lattice solver.
Analogously to the landing maneuver, the analysis for gust is carried out in two steps:

1. an unperturbed trim condition is determined, usually a levelled cruise condition but not necessarily at $n_z = 1$, in clean or flapped configuration, having the angle of attack α_0 and pitch controls as unknowns.

2. the load factor due to the gust is provided and a new angle of attack $\alpha_g = \alpha_0 + \Delta\alpha_g$ is determined.

α_g represents the instant angle of attack due to the gust which is required to balance the inertia forces given by n_z of Eq. (A.11).
In the second trim solution only the plunge degree of freedom is considered so that the instant gust angle of attack can be found. Thus, no rotational acceleration will appear. The value of α is actually not relevant for the designer. α is simply a mean to determine aerodynamic loads which vertically to balance the inertial load from the gust. In this case, the designer is hence invited to focus only on the stress level along the airframe.
It is important to highlight the difference between a pullup maneuver and a gust with the same load factor n_z. The latter indeed features no rotational inertial relief and no balance along the pitch axis.
The gust is defined in the following manner:

```
TRIM=   1 $ Gust
TRIM    1       1       0.4     0.0     SIDES   0       ROLL    0
        PITCH   0       YAW     0       URDD2   0       URDD3   9.81
        URDD4   0       URDD5   0       URDD6   0       flap1r  0
        flap2r  0       aileronr0       rudder1 0       CLIMB   0
        BANK    0       HEAD    0       THRUST  0       VGUST   15.0
```

In this case the maneuver is similar to the definition of a cruise condition, apart from providing `VGUST`. A levelled cruise condition with $n_z = 1$ will be solved at first, determining the angle of attack `ANGLEA` and the deflection of the elevator `elev1r`. Successively, the gust load factor is imposed and a new value for `ANGLEA` is determined. All the controls are kept fixed according to the previous trim solution because the gust is supposed to hit abruptly the whole aircraft.
On the screen the following message is printed:

```
Solving rigid aircraft trim condition...
 - Flight speed (EAS):    136.12 [m/s].
 - Gust speed (EAS):      15 [m/s].
 - Attenuation factor:    0.790805 [].
 - Delta load factor:     1.37735 [].
 - Total load factor:     2.37735 [].
```

```
 - Z acc:      23.3218 [m/s^2].
 - Alpha:      9.92638 [deg].
done.
Solving deformable aircraft trim condition...
 - Z acc:      23.3218 [m/s^2].
 - Alpha:      8.78645 [deg].
done.
```

for both the rigid and the deformable aircraft.
Fig. A.4 shows the final deformed shape for the gust maneuver introduced above.

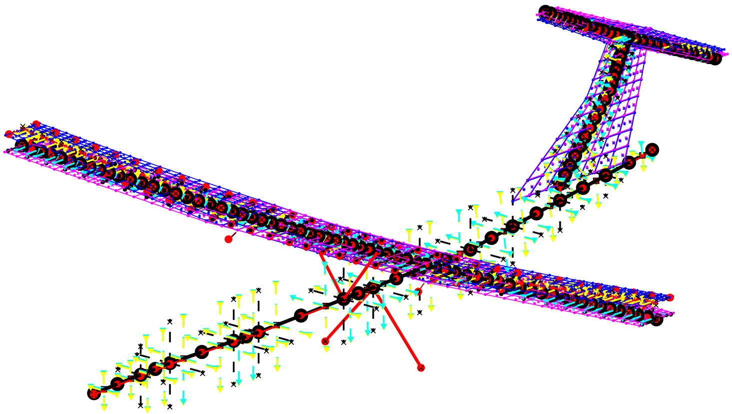
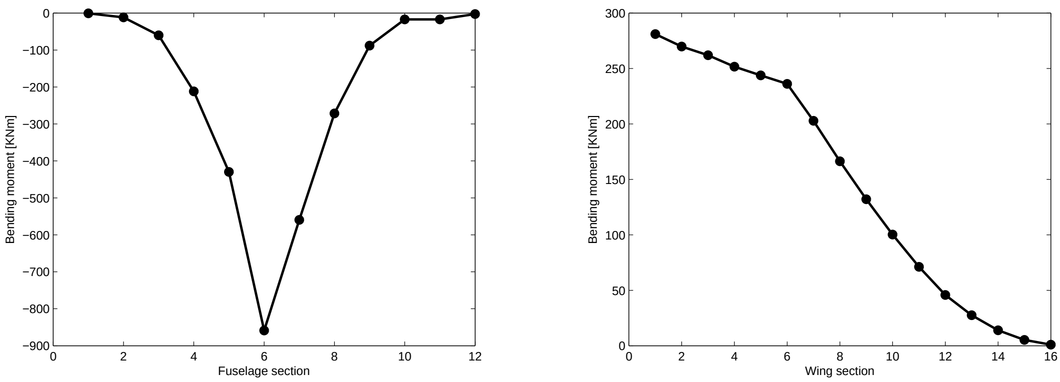


Figure A.4: Final deformed shape for static gust.

Fig. A.5 reports the bending moment along fuselage and semi-wing. The maximum value at wing-fuselage intersection is slightly lower the one determined in the landing maneuver despite the load-factor is higher. Thus, the landing maneuver is the critical one for this simple case considered.



(a) Fuselage bending

(b) Wing bending

Figure A.5: Internal bending along fuselage and wing bar elements.