Aircraft Fight Simulator including Air to Air Missiles

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Agenda

- Wstępny opis projektu
- Analiza wymagań projektowych
- Przegląd technologii
- Rozwiązania inżynierskie
- Dynamika Samolotu
- Dynamika Pocisków
- Możliwość rozszerzeń
- Podsumowanie
- Bibliografia

Wstępny opis projektu

- Aplikacja na komputery stacjonarne
- Stworzenie symulatora dynamiki samolotu
- Stworzenie symulatora dynamiki pocisków
- Moduł wizualizacji lotu
  - Widok pilota
  - Widok z ziemii
- Moduł wizualizacji obliczeń
- Moduł Rozgrywki sieciowej

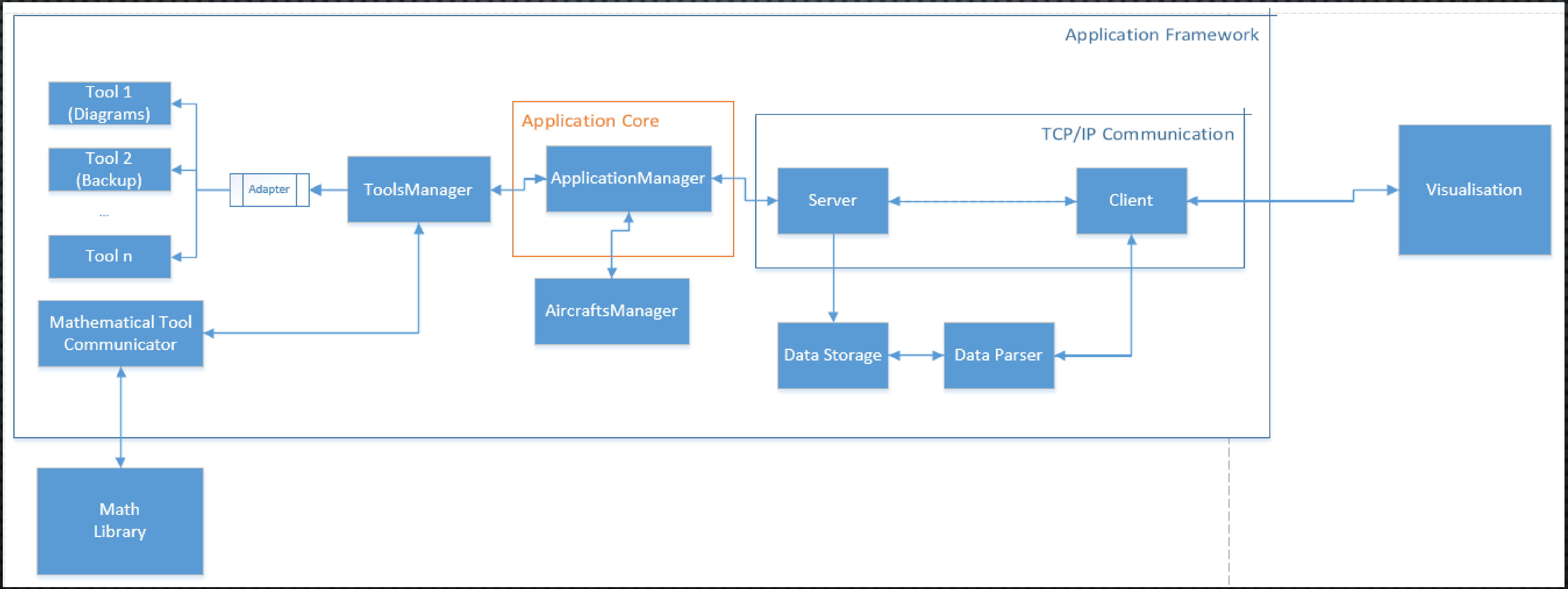
Analiza wymagań projektowych

- Wierny realiom moduł dynamiki
- Niezawodność współdziałania komponentów aplikacji
- Płynność animacji
- Przyjazny, intuicyjny interfejs użytkownika

Przegląd technologii

- Biblioteki matematyczne
  - MatLab
  - Octave
- Wizualizacja
  - Unity
  - .Net – wpf
  - OxyPlot

ROZWIĄZANIA INŻYNIERSKIE – DESIGN APLIKACJI



Rozwiązania inżynierskie – wzorce projektowe

- Obserwator
- Budowniczy
- Strategie
- Fasada
- Adapter
- Nadzorca zadań

DYNAMIKA SAMOLOTU – OZNACZENIA

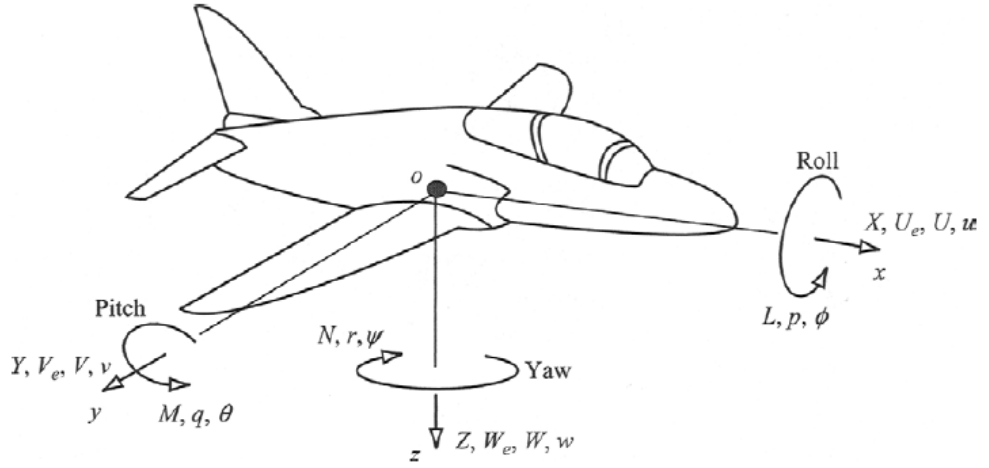
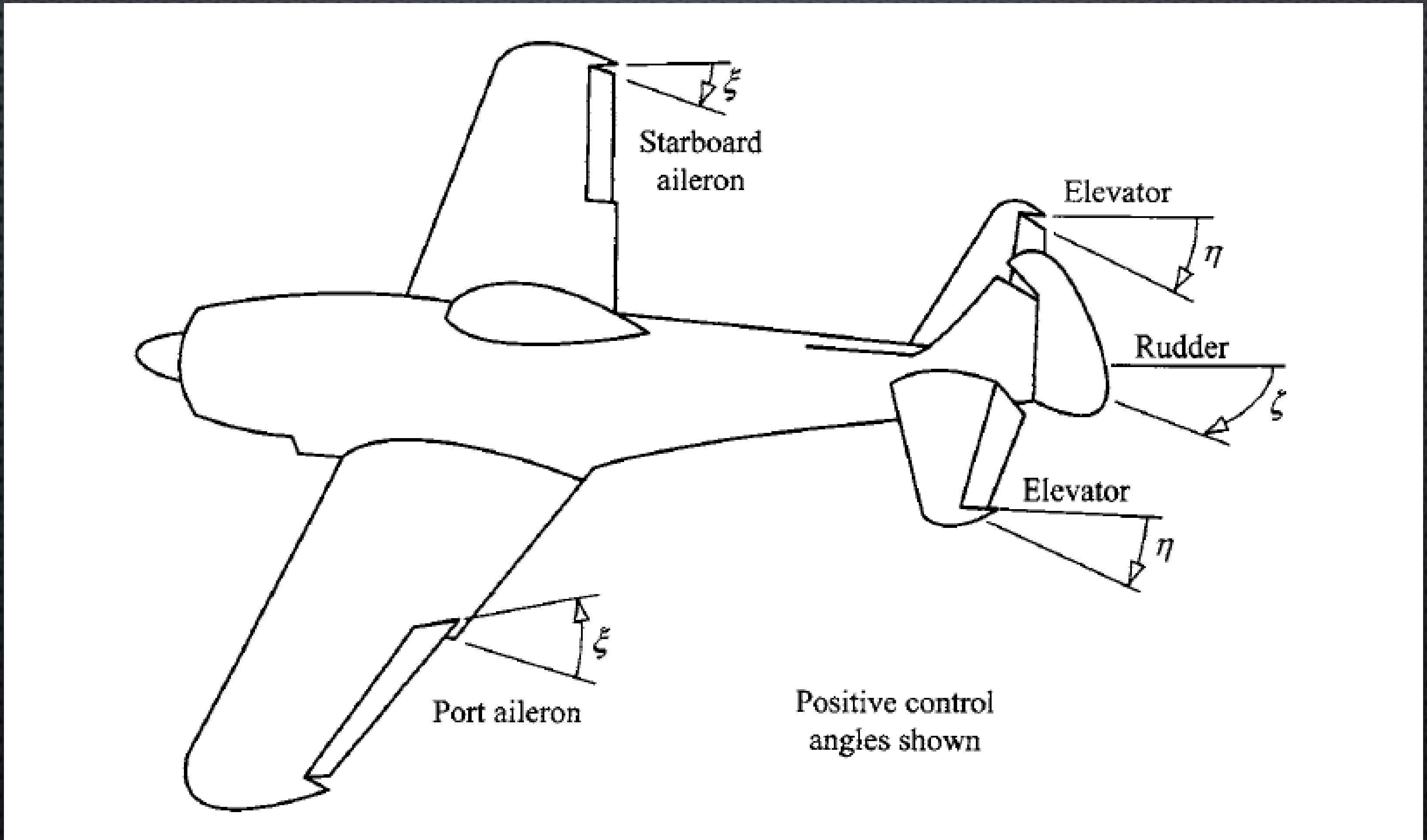


Figure 2.3 *Motion variables notation.*

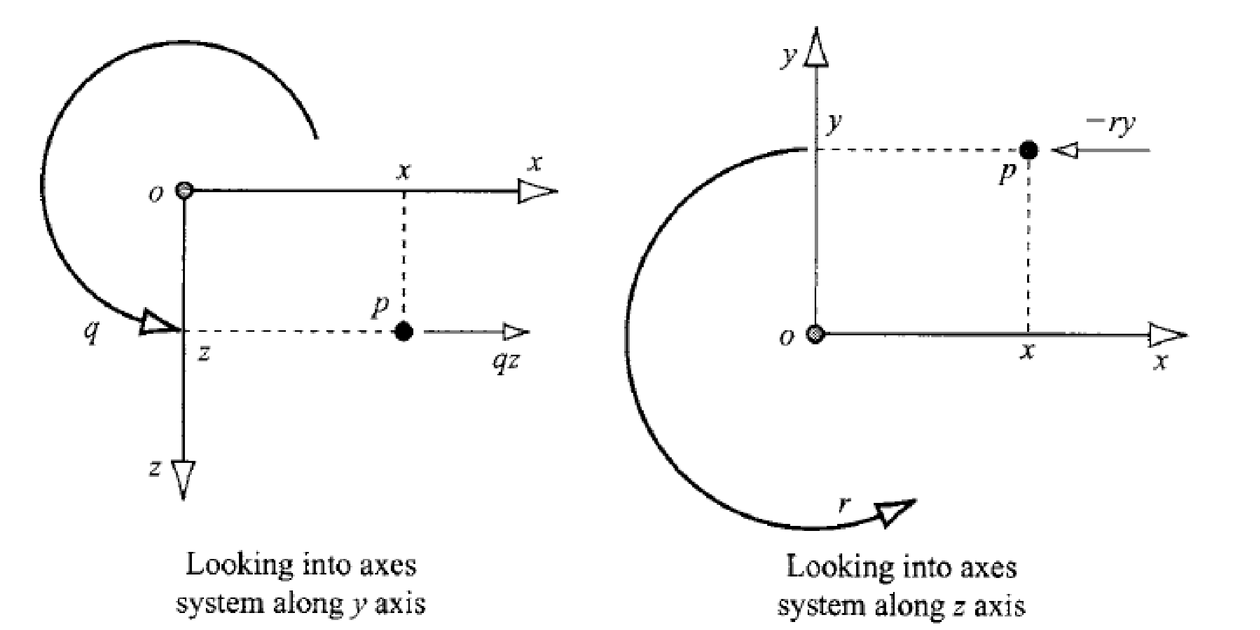
Table 2.1 *Summary of motion variables*

	Trimmed equilibrium			*Perturbed*		
Aircraft axis	*ox*	*oy*	*oz*	*ox*	*oy*	*oz*
Force	0	0	0	X	Y	Z
Moment	0	0	0	L	M	N
Linear velocity	U_e	V_e	W_e	U	V	W
Angular velocity	0	0	0	p	q	r
Attitude	0	θ_e	0	ϕ	θ	ψ

DYNAMIKA SAMOLOTU - STEROWANIE



DYNAMIKA SAMOLOTU – LOKALNE PRĘDKOŚCI PUNKTU

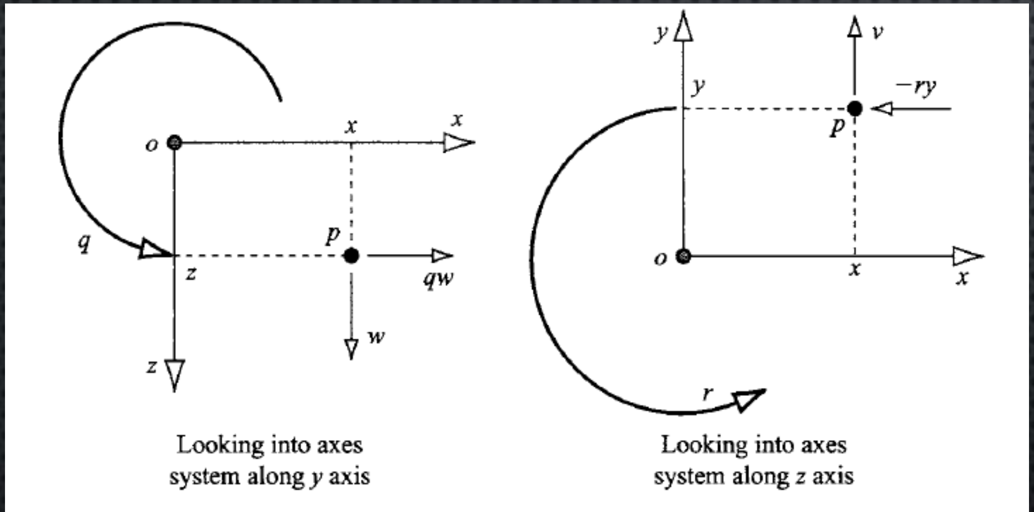


$$u = \dot{x} - ry + qz$$
$$v = \dot{y} - pz + rx$$
$$w = \dot{z} - qx + py$$

$$\dot{x} = \dot{y} = \dot{z} = 0$$

$$u = -ry + qz$$
$$v = -pz + rx$$
$$w = -qx + py$$

DYNAMIKA SAMOLOTU – LOKALNE PRZYSPIESZENIA PUNKTU



$$a_x = \dot{u} - rv + qw$$

$$a_y = \dot{v} - pw + ru$$

$$a_z = \dot{w} - qu + pv$$

DYNAMIKA SAMOLOTU – PRZYSPIESZENIA W UKŁADZIE GLOBALNYM

$$u' = U + u = U - ry + qz$$
$$v' = V + v = V - pz + rx$$
$$w' = W + w = W - qx + py$$

$$a'_x = \dot{u}' - rv' + qw'$$
$$a'_y = \dot{v}' - pw' + ru'$$
$$a'_z = \dot{w}' - qu' + pv'$$

$$\dot{u}' = \dot{U} - \dot{r}y + \dot{q}z$$
$$\dot{v}' = \dot{V} - \dot{p}z + \dot{r}x$$
$$\dot{w}' = \dot{W} - \dot{q}x + \dot{p}y$$

$$a'_x = \dot{U} - rV + qW - x(q^2 + r^2) + y(pq - \dot{r}) + z(pr + \dot{q})$$
$$a'_y = \dot{V} - pW + rU + x(pq + \dot{r}) - y(p^2 + r^2) + z(qr - \dot{p})$$
$$a'_z = \dot{W} - qU + pV + x(pr - \dot{q}) + y(qr + \dot{p}) - z(p^2 + q^2)$$

DYNAMIKA SAMOLOTU – SIŁY I MOMENTY

$$\sum \delta m a'_x = X$$
$$\sum \delta m a'_y = Y$$
$$\sum \delta m a'_z = Z$$

$$\sum \delta m x = \sum \delta m y = \sum \delta m z$$

$$m(\dot{U} - rV + qW) = X$$
$$m(\dot{V} - pW + rU) = Y$$
$$m(\dot{W} - qU + pV) = Z$$

$$I_x = \sum \delta m(y^2 + z^2) \qquad I_{xy} = \sum \delta m x y$$
$$I_y = \sum \delta m(x^2 + z^2) \qquad I_{xz} = \sum \delta m x z$$
$$I_z = \sum \delta m(x^2 + y^2) \qquad I_{yz} = \sum \delta m y z$$

$$\sum \delta m(y a'_z - z a'_y) = L$$

$$\dot{p} \sum \delta m(y^2 + z^2) + qr \sum \delta m(y^2 - z^2) + (r^2 - q^2) \sum \delta m y z$$
$$- (pq + \dot{r}) \sum \delta m x z + (pr - \dot{q}) \sum \delta m x y = L$$

DYNAMIKA SAMOLOTU – MOMENTY UPROSZCZENIA

$$I_x\dot{p} - (I_y - I_z)qr + I_{xy}(pr - \dot{q}) - I_{xz}(pq + \dot{r}) + I_{yz}(r^2 - q^2) = L$$

$$I_y\dot{q} - (I_x - I_z)pr + I_{yz}(pq - \dot{r}) + I_{xz}(p^2 - r^2) + I_{xy}(qr + \dot{p}) = M$$

$$I_z\dot{r} - (I_x - I_y)pq - I_{yz}(pr + \dot{q}) + I_{xz}(qr - \dot{p}) + I_{xy}(q^2 - p^2) = N$$

$$I_{xy} = 0$$
$$I_{yz} = 0$$

$$I_x\dot{p} - (I_y - I_z)qr - I_{xz}(pq + \dot{r}) = L$$
$$I_y\dot{q} - (I_x - I_z)pr + I_{xz}(p^2 - r^2) = M$$
$$I_z\dot{r} - (I_x - I_y)pq + I_{xz}(qr - \dot{p}) = N$$

DYNAMIKA SAMOLOTU – ZEWNĘTRZNE SIŁY I MOMENTY

$$m(\dot{U} - rV + qW) = X_a + X_g + X_c + X_p + X_d$$
$$m(\dot{V} - pW + rU) = Y_a + Y_g + Y_c + Y_p + Y_d$$
$$m(\dot{W} - qU + pV) = Z_a + Z_g + Z_c + Z_p + Z_d$$

$$I_x\dot{p} - (I_y - I_z)qr - I_{xz}(pq + \dot{r}) = L_a + L_g + L_c + L_p + L_d$$
$$I_y\dot{q} + (I_x - I_z)pr + I_{xz}(p^2 - r^2) = M_a + M_g + M_c + M_p + M_d$$
$$I_z\dot{r} - (I_x - I_y)pq + I_{xz}(qr - \dot{p}) = N_a + N_g + N_c + N_p + N_d$$

DYNAMIKA SAMOLOTU – ZEWNĘTRZNE SIŁY I MOMENTY – LINEARYZACJA

$$X_d = Y_d = Z_d = L_d = M_d = N_d = 0$$

$$V_e = 0$$

$$\begin{aligned} U &= U_e + u \\ V &= V_e + v = v \\ W &= W_e + w \end{aligned}$$

$$\begin{aligned} m(\dot{u} + qW_e) &= X_a + X_g + X_c + X_p \\ m(\dot{v} - pW_e + rU_e) &= Y_a + Y_g + Y_c + Y_p \\ m(\dot{w} - qU_e) &= Z_a + Z_g + Z_c + Z_p \\ I_x\dot{p} - I_{xz}\dot{r} &= L_a + L_g + L_c + L_p \\ I_y\dot{q} &= M_a + M_g + M_c + M_p \\ I_z\dot{r} - I_{xz}\dot{p} &= N_a + N_g + N_c + N_p \end{aligned}$$

DYNAMIKA SAMOLOTU – ZEWNĘTRZNE SIŁY I MOMENTY – ODDZIAŁYWANIE GRAWITACYJNE

$$L_g = M_g = N_g = 0$$

$$\begin{bmatrix} X_{g_e} \\ X_{g_e} \\ X_{g_e} \end{bmatrix} = \begin{bmatrix} -mg\sin\theta_e \\ 0 \\ mg\cos\theta_e \end{bmatrix}$$

$$\begin{bmatrix} X_g \\ X_g \\ X_g \end{bmatrix} = \begin{bmatrix} 1 & \psi & -\theta \\ -\psi & 1 & \phi \\ \theta & -\phi & 1 \end{bmatrix} \begin{bmatrix} X_{g_e} \\ X_{g_e} \\ X_{g_e} \end{bmatrix}$$

$$\begin{aligned} X_g &= -mg\sin\theta_e - mg\theta\cos\theta_e \\ Y_g &= mg\psi\sin\theta_e + mg\phi\cos\theta_e \\ Z_g &= mg\cos\theta_e - mg\theta\sin\theta_e \end{aligned}$$

DYNAMIKA SAMOLOTU – ZEWNĘTRZNE SIŁY I MOMENTY – SIŁA AERODYNAMICZNA

$$
\begin{aligned}
X_a = X_{a_e} &+ \left(\frac{\partial X}{\partial u}u + \frac{\partial^2 X}{\partial u^2}\frac{u^2}{2!} + \frac{\partial^3 X}{\partial u^3}\frac{u^3}{3!} + \frac{\partial^4 X}{\partial u^4}\frac{u^4}{4!} + \ldots\right) \\
&+ \left(\frac{\partial X}{\partial v}v + \frac{\partial^2 X}{\partial v^2}\frac{v^2}{2!} + \frac{\partial^3 X}{\partial v^3}\frac{v^3}{3!} + \frac{\partial^4 X}{\partial v^4}\frac{v^4}{4!} + \ldots\right) \\
&+ \left(\frac{\partial X}{\partial w}w + \frac{\partial^2 X}{\partial w^2}\frac{w^2}{2!} + \frac{\partial^3 X}{\partial w^3}\frac{w^3}{3!} + \frac{\partial^4 X}{\partial w^4}\frac{w^4}{4!} + \ldots\right) \\
&+ \left(\frac{\partial X}{\partial p}p + \frac{\partial^2 X}{\partial p^2}\frac{p^2}{2!} + \frac{\partial^3 X}{\partial p^3}\frac{p^3}{3!} + \frac{\partial^4 X}{\partial p^4}\frac{p^4}{4!} + \ldots\right) \\
&+ \left(\frac{\partial X}{\partial q}q + \frac{\partial^2 X}{\partial q^2}\frac{q^2}{2!} + \frac{\partial^3 X}{\partial q^3}\frac{q^3}{3!} + \frac{\partial^4 X}{\partial q^4}\frac{q^4}{4!} + \ldots\right) \\
&+ \left(\frac{\partial X}{\partial r}r + \frac{\partial^2 X}{\partial r^2}\frac{r^2}{2!} + \frac{\partial^3 X}{\partial r^3}\frac{r^3}{3!} + \frac{\partial^4 X}{\partial r^4}\frac{r^4}{4!} + \ldots\right) \\
&+ terms\ in\ \dot{u}, \dot{v}, \dot{w}, \dot{p}, \dot{q}, \dot{r} \\
&+ terms\ in\ higher\ order\ derivatives
\end{aligned}
$$

$$X_a = X_{a_e} + \frac{\partial X}{\partial u}u + \frac{\partial X}{\partial v}v + \frac{\partial X}{\partial w}w + \frac{\partial X}{\partial p}p + \frac{\partial X}{\partial q}q + \frac{\partial X}{\partial r}r + \frac{\partial X}{\partial \dot{w}}\dot{w}$$

$$X_a = X_{a_e} + \mathring{X}_u u + \mathring{X}_v v + \mathring{X}_w w + \mathring{X}_p p + \mathring{X}_q q + \mathring{X}_r r + \mathring{X}_{\dot{w}}\dot{w}$$

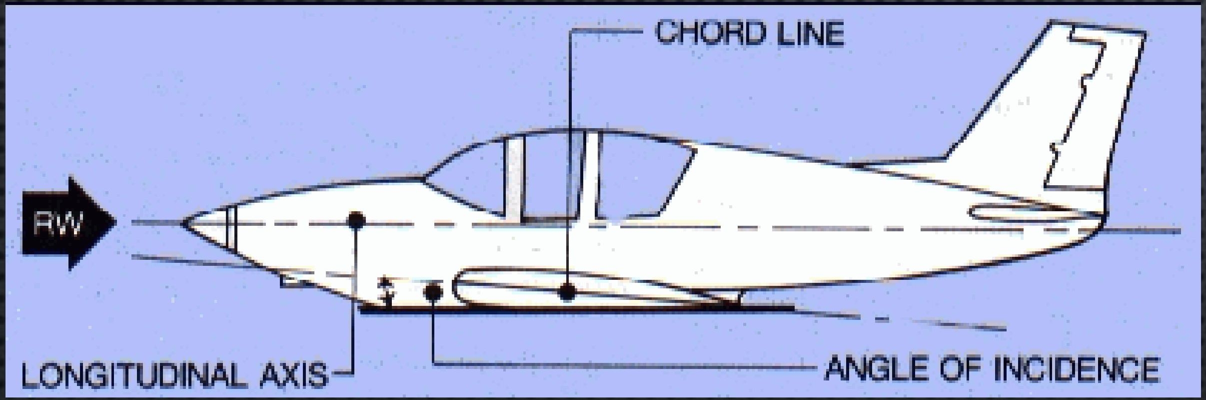
DYNAMIKA SAMOLOTU – ZEWNĘTRZNE SIŁY I MOMENTY – AERODYNAMIKA STEROWANIA I SIŁA NAPĘDOWA

$$M_c = \frac{\partial M}{\partial \xi}\xi + \frac{\partial M}{\partial \eta}\eta + \frac{\partial M}{\partial \zeta}\zeta$$

$$M_c = \mathring{M}_\xi \xi + \mathring{M}_\eta \eta + \mathring{M}_\zeta \zeta$$

$$Z_p = \mathring{Z}_\tau \tau$$

DYNAMIKA SAMOLOTU – PODZIAŁ RÓWNAŃ RUCHU



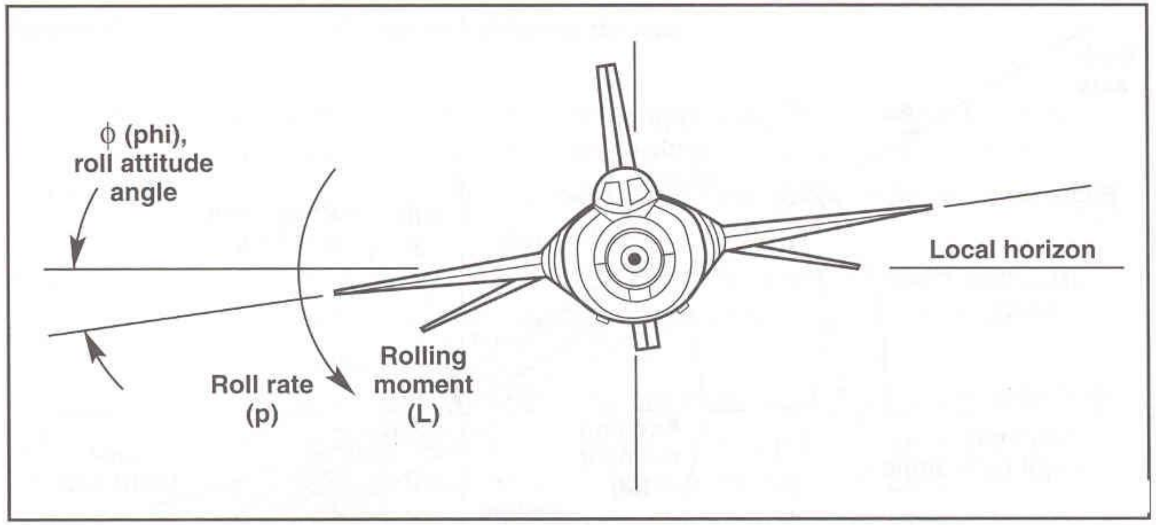


Fig. D-4. Diagram showing lateral terms.

DYNAMIKA SAMOLOTU – PODZIAŁ RÓWNAŃ RUCHU

$$\mathring{X}_v = \mathring{X}_p = \mathring{X}_r = \mathring{Z}_v = \mathring{Z}_p = \mathring{Z}_r = \mathring{M}_v = \mathring{M}_p = \mathring{M}_r = 0$$

$$\mathring{X}_\xi = \mathring{X}_\zeta = \mathring{Z}_\xi = \mathring{Z}_\zeta = \mathring{M}_\xi = \mathring{M}_\zeta = 0$$

$$\begin{aligned}
m\dot{u} - \mathring{X}_u u - \mathring{X}_{\dot{w}}\dot{w} - \mathring{X}_w w - (\mathring{X}_q - mW_e)q + mg\theta\cos\theta_e &= \mathring{X}_\eta\eta + \mathring{X}_\tau\tau \\
-\mathring{Z}_u u + (m - \mathring{Z}_{\dot{w}})\dot{w} - \mathring{Z}_w w - (\mathring{Z}_q + mU_e)q + mg\theta\sin\theta_e &= \mathring{Z}_\eta\eta + \mathring{Z}_\tau\tau \\
-\mathring{M}_u u - \mathring{M}_{\dot{w}}\dot{w} - \mathring{M}_w w + I_y\dot{q} - \mathring{M}_q q &= \mathring{M}_\eta\eta + \mathring{M}_\tau\tau
\end{aligned}$$

$$\mathring{Y}_u = \mathring{Y}_{\dot{w}} = \mathring{Y}_w = \mathring{Y}_q = \mathring{L}_u = \mathring{L}_{\dot{w}} = \mathring{L}_w = \mathring{L}_q = \mathring{N}_u = \mathring{N}_{\dot{w}} = \mathring{N}_w = \mathring{N}_q = 0$$

$$\mathring{Y}_\eta = \mathring{Y}_\tau = \mathring{L}_\eta = \mathring{L}_\tau = \mathring{N}_\eta = \mathring{N}_\tau = 0$$

$$\begin{aligned}
m\dot{v} - \mathring{Y}_v v - (\mathring{Y}_p + mW_e)p - (\mathring{Y}_r - mU_e)r \\
-mg\phi\cos\theta_e - mg\psi\sin\theta_e &= \mathring{Y}_\xi\xi + \mathring{Y}_\zeta\zeta \\
-\mathring{L}_v v + I_x\dot{p} - \mathring{L}_p p - I_{xz}\dot{r} - \mathring{L}_r r &= \mathring{L}_\xi\xi + \mathring{L}_\zeta\zeta \\
-\mathring{N}_v v + I_{xz}\dot{p} - \mathring{N}_p p + I_z\dot{r} - \mathring{N}_r r &= \mathring{N}_\xi\xi + \mathring{N}_\zeta\zeta
\end{aligned}$$

DYNAMIKA SAMOLOTU – RÓWNANIE STANU – WERSJA LONGITUDINAL

$$M\dot{x}(t) = A'x(t) + B'u(t)$$

$$x^T(t) = [u\ w\ q\ \theta] \quad u^T(t) = [\eta\ \tau]$$

$$M = \begin{bmatrix} m & -\mathring{X}_{\dot{w}} & 0 & 0 \\ 0 & (m - \mathring{Z}_{\dot{w}}) & 0 & 0 \\ 0 & -\mathring{M}_{\dot{w}} & I_y & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A' = \begin{bmatrix} \mathring{X}_u & \mathring{X}_w & (\mathring{X}_q - mW_e) & -mg\cos\theta_e \\ \mathring{Z}_u & \mathring{Z}_w & (\mathring{Z}_q + mU_e) & -mg\sin\theta_e \\ \mathring{M}_u & \mathring{M}_w & \mathring{M}_q & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

$$B' = \begin{bmatrix} \mathring{X}_\eta & \mathring{X}_\tau \\ \mathring{Z}_\eta & \mathring{Z}_\tau \\ \mathring{M}_\eta & \mathring{M}_\tau \\ 0 & 0 \end{bmatrix}$$

$$\dot{x}(t) = Ax(t) + Bu(t) \tag{3.36}$$

$$A = \begin{bmatrix} \frac{\mathring{X}_u}{m} + \frac{\mathring{X}_{\dot{w}}\mathring{Z}_u}{m(m-\mathring{Z}_{\dot{w}})} & \frac{\mathring{X}_w}{m} + \frac{\mathring{X}_{\dot{w}}\mathring{Z}_w}{m(m-\mathring{Z}_{\dot{w}})} & \frac{\mathring{X}_q - mW_e}{m} + \frac{(\mathring{Z}_q + mU_e)\mathring{X}_{\dot{w}}}{m(m-\mathring{Z}_{\dot{w}})} & -g\cos\theta e - \frac{\mathring{X}_{\dot{w}} g \sin\theta_e}{m-\mathring{Z}_{\dot{w}}} \\ \frac{\mathring{Z}_u}{m-\mathring{Z}_{\dot{w}}} & \frac{\mathring{Z}_w}{m-\mathring{Z}_{\dot{w}}} & \frac{\mathring{Z}_q + mU_e}{m-\mathring{Z}_{\dot{w}}} & \frac{-mg\sin\theta_e}{m-\mathring{Z}_{\dot{w}}} \\ \frac{\mathring{M}_{\dot{w}}\mathring{Z}_u}{I_y(m-\mathring{Z}_{\dot{w}})} + \frac{\mathring{M}_u}{I_y} & \frac{\mathring{M}_{\dot{w}}\mathring{Z}_w}{I_y(m-\mathring{Z}_{\dot{w}})} + \frac{\mathring{M}_u}{I_y} & \frac{(\mathring{Z}_q + mU_e)\mathring{M}_{\dot{w}}}{I_y(m-\mathring{Z}_{\dot{w}})} + \frac{\mathring{M}_q}{I_y} & \frac{-\mathring{M}_{\dot{w}} mg\sin\theta_e}{I_y(m-\mathring{Z}_{\dot{w}})} \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} \frac{\mathring{X}_\eta}{m} + \frac{\mathring{X}_{\dot{w}}\mathring{Z}_\eta}{m(m-\mathring{Z}_{\dot{w}})} & \frac{\mathring{X}_\tau}{m} + \frac{\mathring{X}_{\dot{w}}\mathring{Z}_\tau}{m(m-\mathring{Z}_{\dot{w}})} \\ \frac{\mathring{Z}_\eta}{m-\mathring{Z}_{\dot{w}}} & \frac{\mathring{Z}_\tau}{m-\mathring{Z}_{\dot{w}}} \\ \frac{\mathring{M}_{\dot{w}}\mathring{Z}_\eta}{I_y(m-\mathring{Z}_{\dot{w}})} + \frac{\mathring{M}_\eta}{I_y} & \frac{\mathring{M}_{\dot{w}}\mathring{Z}_\tau}{I_y(m-\mathring{Z}_{\dot{w}})} + \frac{\mathring{M}_\tau}{I_y} \\ 0 & 0 \end{bmatrix}$$

DYNAMIKA SAMOLOTU – RÓWNANIE STANU – WERSJA LONGITUDINAL – PRZYBLIŻENIA

$$M=\begin{bmatrix} m' & -\frac{X_{\dot{w}}c}{V_0} & 0 & 0\\ 0 & (m'-\frac{Z_{\dot{w}}c}{V_0}) & 0 & 0\\ 0 & -\frac{M_{\dot{w}}c}{V_0} & I'_y & 0\\ 0 & 0 & 0 & 1\end{bmatrix}$$

$$A'=\begin{bmatrix} X_u & X_w & (X_qc-\dot{m}W_e) & -\dot{m}g\cos\theta_e\\ Z_u & Z_w & (X_qc-\dot{m}U_e) & -\dot{m}g\sin\theta_e\\ M_u & M_w & M_qc & 0\\ 0 & 0 & 1 & 0\end{bmatrix}$$

$$B'=\begin{bmatrix} V_0X_\eta & V_0X_\tau\\ V_0Z_\eta & V_0Z_\tau\\ V_0M_\eta & V_0M_\tau\\ 0 & 0\end{bmatrix}$$

$$m'=\frac{m}{\frac{1}{2}\rho V_0 S},\ I'_y=\frac{I_y}{\frac{1}{2}\rho V_0 Sc},\ U_e=V_0\cos\theta_e,\ W_e=V_0\sin\theta_e$$

$$A=\begin{bmatrix} \frac{X_u}{m'}-\frac{X_{\dot{w}}Z_uc}{m'(Z_{\dot{w}}c-V_0m')} & \frac{X_w}{m'}-\frac{X_{\dot{w}}Z_wc}{m'(Z_{\dot{w}}c-V_0m')} & \frac{X_qc-W_em'}{m'}-\frac{X_{\dot{w}}c(Z_qc+U_em')}{m'(Z_{\dot{w}}c-V_0m')} & \frac{X_{\dot{w}}cg\sin\theta_e}{Z_{\dot{w}}c-V_0m'}-g\cos\theta_e\\ -\frac{V_0Z_u}{Z_{\dot{w}}c-V_0m'} & -\frac{V_0Z_w}{Z_{\dot{w}}c-V_0m'} & -\frac{V_0(Z_qc+U_em')}{Z_{\dot{w}}c-V_0m'} & \frac{V_0gm'\sin\theta_e}{Z_{\dot{w}}c-V_0m'}\\ \frac{M_u}{I'_y}-\frac{M_{\dot{w}}Z_uc}{I'_y(Z_{\dot{w}}c-V_0m')} & \frac{M_w}{I'_y}-\frac{M_{\dot{w}}Z_wc}{I'_y(Z_{\dot{w}}c-V_0m')} & \frac{M_qc}{I'_y}-\frac{M_{\dot{w}}c(Z_qc+U_em')}{I'_y(Z_{\dot{w}}c-V_0m')} & \frac{M_{\dot{w}}cgm'\sin\theta_e}{I'_y(Z_{\dot{w}}c-V_0m')}\\ 0 & 0 & 1 & 0\end{bmatrix}$$

$$B=\begin{bmatrix} \frac{V_0X_\eta}{m'}-\frac{V_0X_{\dot{w}}Z_\eta c}{m'(Z_{\dot{w}}c-V_0m')} & \frac{V_0X_\tau}{m'}-\frac{V_0X_{\dot{w}}Z_\tau c}{m'(Z_{\dot{w}}c-V_0m')}\\ -\frac{V_0^2Z_\eta}{m'(Z_{\dot{w}}c-V_0m')} & -\frac{V_0^2Z_\tau}{m'(Z_{\dot{w}}c-V_0m')}\\ \frac{V_0M_\eta}{I'_y}-\frac{V_0M_{\dot{w}}Z_\eta c}{I'_y(Z_{\dot{w}}c-V_0m')} & \frac{V_0M_\tau}{I'_y}-\frac{V_0M_{\dot{w}}Z_\tau c}{I'_y(Z_{\dot{w}}c-V_0m')}\\ 0 & 0\end{bmatrix}$$

DYNAMIKA SAMOLOTU – RÓWNANIE STANU – WERSJA LATERAL – PRZYBLIŻENIA

$$x^T(t) = [v \; p \; r \; \phi \; \psi] \quad u^T(t) = [\xi \; \zeta]$$

$$M = \begin{bmatrix} m' & 0 & 0 & 0 & 0 \\ 0 & I'_x & -I'_{xz} & 0 & 0 \\ 0 & -I'_{xz} & I'_z & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A' = \begin{bmatrix} Y_v & (Y_p b + m'W_e) & (Y_r b - m'U_e) & m'g\cos\theta_e & m'g\sin\theta_e \\ L_v & L_p b & L_r b & 0 & 0 \\ N_v & N_p b & N_r b & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix}$$

$$B' = \begin{bmatrix} V_0 Y_\xi & V_0 Y_\zeta \\ V_0 L_\xi & V_0 L_\zeta \\ V_0 N_\xi & V_0 N_\zeta \\ 0 & 0 \\ 0 & 0 \end{bmatrix}$$

$$m' = \frac{m}{\frac{1}{2}\rho V_0 S}, \;\; I'_x = \frac{I_x}{\frac{1}{2}\rho V_0 S b}, \;\; I'_z = \frac{I_z}{\frac{1}{2}\rho V_0 S b}, \;\; I'_{xz} = \frac{I_{xz}}{\frac{1}{2}\rho V_0 S b}$$

$$A = \begin{bmatrix} \frac{SV_0 Y_v \rho}{2m} & \frac{V_0(SY_p b\rho + 2m\sin\theta_e)}{2m} & \frac{V_0(SY_r b\rho - 2m\cos\theta_e)}{2m} & g\cos\theta_e & g\sin\theta_e \\ -\frac{SV_0 b\rho(I_z L_v + I_{xz} N_v)}{2(I_{xz}^2 - I_x I_z)} & -\frac{SV_0 b^2\rho(I_z L_p + I_{xz} N_p)}{2(I_{xz}^2 - I_x I_z)} & -\frac{SV_0 b^2\rho(I_z L_r + I_{xz} N_r)}{2(I_{xz}^2 - I_x I_z)} & 0 & 0 \\ -\frac{SV_0 b\rho(I_{xz} L_v + I_x N_v)}{2(I_{xz}^2 - I_x I_z)} & -\frac{SV_0 b^2\rho(I_{xz} L_p + I_x N_p)}{2(I_{xz}^2 - I_x I_z)} & -\frac{SV_0 b^2\rho(I_{xz} L_r + I_x N_r)}{2(I_{xz}^2 - I_x I_z)} & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} \frac{SV_0^2 Y_\xi \rho}{2m} & \frac{SV_0^2 Y_\zeta \rho}{2m} \\ -\frac{SV_0^2 b\rho(I_z L_\xi + I_{xz} N_\xi)}{2(I_{xz}^2 - I_x I_z)} & -\frac{SV_0^2 b\rho(I_z L_\zeta + I_{xz} N_\zeta)}{2(I_{xz}^2 - I_x I_z)} \\ -\frac{SV_0^2 b\rho(I_{xz} L_\xi + I_x N_\xi)}{2(I_{xz}^2 - I_x I_z)} & -\frac{SV_0^2 b\rho(I_{xz} L_\zeta + I_x N_\zeta)}{2(I_{xz}^2 - I_x I_z)} \\ 0 & 0 \\ 0 & 0 \end{bmatrix}$$

Możliwości rozszerzeń

- Rozszerzenie aplikacji na inne platformy
  - Mobilne
  - VR – Google Glass, VR Gear, Oculus VR
- Rozbudowywanie modelu dynamiki
  - Uwzględnienie oporów powietrza
  - Nierównomierny rozkład masy samolotu, masa funkcją czasu
  - Uwzględnienie grawitacji innych obiektów

PODSUMOWANIE

- Elementy pozostałe do implementacji:
  - Skończenie implementacji dynamiki samolotu
  - Skończenie modułu rozgrywki sieciowej
  - Skończenie modułu wizualizacji
  - Stworzenie dynamiki pocisków
- Problemy:
  - Brak czasu ☺
  - Brak kompletnych danych dotyczących modeli
  - Brak specjalistycznej wiedzy o sterowaniu samolotem
  - Nie wiemy jak wygląda dynamika pocisku

BIBLIOGRAFIA

- *K.Marciniak* materiały wykładowe projektowania rzeczywistości wirtualnej
- *M.Cook* Flight Dynamics Principles, 2nd Edition A Linear Systems Approach to Aircraft Stability and Control
- *R.K.Heffley, W.F.Jewell* Aircraft Handling Qualities Data