Flight Dynamics and Control Modeling with System Identification Validation of the Sikorsky X2 Technology¥ Demonstrator

Cody Fegely
6 H Q L R U   (Q J L Q H H
+ D Q G O L Q J   4 X D O L W L H V
6 L N R U V N \ $ L U F U D I W
6 W U D W I R U G   & 7   8

Ondrej Juhasz
5 H H D U F K $ V V R F L D
6 D Q   - R V H   6 W D W H   8
8 6 $ U P \ $ Y L D W L R
' H Y H O R S P H Q W   ' L U H F W
0 R I I H W W   ) L H O G   & $

PRGHV   IODSZLVH   FKRUGZLVH   WRUVLRQ DUH XVHG LQ WKH
PRGHO $ QRQOLQHDU XQVWHDG\ DLU ORDGV PRGHO ZDV XVHG LQ WKH
66*+ ; 7' PRGHO ZKLFK ZDV EDVHG RQ /HLVKPDQ %HGGRHV
PRGHO LQ 5HI   WRU5D

WKH VWDWH VSDFH PRGHO DV H[WUDFWHG XVLQJ SHUWXUEDWLRQ
PHWKRGV +HO DQG +HOL80 DFFXUDWHO\ SUHGLFW WKH SLWFK
UHVSRQVH WRR P])RU WKH UROO UHVSRQVH ERWK
PRGHOV XQGHU SUHGLFW WKH DEVROXWH JDLQ IURP WR
*HQ+HO DQG +HOL80 ERWK FRUUHFWO\ SUHGLFW WKH URWRU
UHJUHVVLYH IODS PRGH]DWRWDSSURSHOO\WHO\
SUHGLFW WKH IUHTXHQF\ RI WKH OHDG ODJ GLSROH WR EH +] ZKLOH
LW LV FORVHU WR +] LQ IOLJKW GDWD 7KH PRGHOV SUHGLFW
GLIIHUHQW IUHTXHQFLHV IRU WKH KRYHULQJ FXELF ± +]

&UXLVH 5HVSRQVHV

Figure 10 D Ga Figure 11 VKRZ WKH EDUH DLUIUDPH IUHTXHQF\
UHVSRQVH IRU SLWFK DQG UROO LQ FUXLVH *HQ+HO SUHGLFWV WKH
SLWFK UHVSRQVH ZHOO DW +]NQRWV EHWZHHQ WR
+HOL80 SUHGLFWV D VLPLODU UHVSRQVH WR *HQ+HO DW VKRUW WHUP
UHVSRQVH IUHTXHQFLHV WKH VDPSOH WDLO URWRU
PRGHO LQ +HOL80 PD\ EH WKH FDXVH RI WKH GLVFUHSDQF\
EHORZ +] 7KH GDWD TXDOLW\ LV OLPLWHG WR +] LQ WKLV D[LV

+HOL80 DFFXUDWHO\ SUHGLFWV WKH UROO UHVSRQVH DW NQRWV
ZKLOH *HQ+HO VOLJKWO\ XQGHU SUHGLFWV WKH JDLQ %RWK PRGHOV
SUHGLFW WKH UHJUHVVLYH IODS PRGH WR EH DURXQG +] 7KH
OHDG ODJ GLSROH LV QRW DV DSSDUHQW LQ WKH FUXLVH UHVSRQVHV DV
ZDV LQ KRYHU

Figure 7: Pilot Input for Cruise Pitch Frequency
Response

&RPSUHKHQVLYH VLPXODWLRQ PRGHOV
RI LQSXW SDUDPHWHUV IRU EODGH DQ
RI WKHVH SDUDPHWHUV DUH GLIILFXOW
DORQH GXULQJ DFWXDO IOLJKW WHVV
IRUPXODWLRQ RI WKH PRGHO VLPSOLI
LQWURGXFLQJ XQFHUWDLQW\ LQWR W
SDUDPHWHUV 7KLV LV HVSHFLDOO\
FRQILJXUDWLRQV OLNH WKH ; 7' WKDW
VLQJOH PDLQ URWRU KHOLFRSWHUV 6
KHUHLQ WR LPSURYH WKH FRUUHODWLR
GDWD

<u>,GHQWLILFDWLRQ RI +RYHU 5HJUHVVLYH</u>

$QDO\WLFDOO\ GHULYHG FRXSOHG IX
HTXDWLRQV RI PRWLRQ IRU WKH 6LNR
ZRUN E\ &KHQ Z(H)UH XVHG WR GHULYH I
EDVHG XSGDWHV WR WKH PDWK PRGHO
XVH D KLQJH RIIVHW IODS VSULQJ WR
RI WKH KLQJHOHVV 6LNRUVN\ ; 7' URW
ERG\ HTXDWLRQV RI PRWLRQ DUH IRU I

$$-\frac{\Omega^2\gamma}{2}\left(\frac{1}{4}-\frac{\epsilon}{3}\right)\begin{bmatrix}0 & 0\\ 0 & 0\\ \theta_{\delta_{lon}}\cos(\Gamma) & \theta_{\delta_{lat}}\sin(\Gamma)\\ -\theta_{\delta_{lon}}\sin(\Gamma) & \theta_{\delta_{lat}}\cos(\Gamma)\\ 0 & 0\\ 0 & 0\end{bmatrix}\begin{Bmatrix}\delta_{lon}\\ \delta_{lat}\end{Bmatrix}$$

ZKHUH 5HI   DQG 5HI

$Q HTXLYDOHQW VHW RI HTXDWLRQV H[
NH\ GULYHUV RI G\QDPLFV LQ WKH IU
UHJUHVVLYH IODS PRGH DUH WKH FRXS
DQG URWRU G\QD PLFV OHDG ODJ URWRU /EODGH
IUHTXHQ 7KH VWHUP (TQ   LV KLJKO\
RQ UROO LDOOHG UWLKH I,ODS ZKHFK HLQ\FEDVH
RQWKH HIIHFWLYH KLQJH RIIVHO DW HQ DQ
(TQ   7KH ; 7' KDV D YHU\ VPDOO IXV
   VOXWJ 6PDOO HUURUV LQ WKLV YDOX
LPSDFW RQ WKH HTXDWLRQV RI PRWLR
SUHGLFWLRQ RI WKH FRXSOHG URWRU

X2TD CLOSED-LOOP ANALYSIS

Hover: Frequency Domain

Figure 18: Lateral Broken-Loop Response

Figure 16: Lateral Control System Response
to Roll Rate

Figure 19: Longitudinal Broken-Loop Response

Figure 17: Longitudinal Control System Response
to Pitch Rate

<u>C L O S E D L O O P A N D B A N D W I D T H</u>

T H E C L O S E D L O O ~~Figure 21~~ S R R W H Q D L U F U D I W

Cruise: Time Domain

DISCUSSION AND CONCLUSIONS

9DOLGDWHG SK\VLFV EDVHG IOLJKW G\QDPLFV PRGHOV DUH
LQVWUX LPW&H\WDDO UFUDIW GHVLJQ SURFHVV DQG DUH XVHG IRU
ORDG SUHGLFWLRQ FRQWURO V\VWHP GHVLJQ DQG KDQGOLQJ
TXDOLWLHV DQDO\VLV 7KHVH PRGHOV SURYLGH YLWDO SUHGLFWLYH
FDSDELOLW\ IRU ERWK IXWXUH DQG IRRORZ RQ FRQFHSWV

7KLV SDSHU SUHVHQWHG WKH GHYHORSPHQW DQG YDOLGDWLRQ RI WZR
KLJK RUGHU PDWK PRGHOV XVHG IRU URWRUFUDIW IOLJKW G\QDPLFV
PRGHOLQJ %RWK WKH 6LNRUVN\ *HQ+HO DQG +HOL8P PRGHOV
KDYH KDG ORQJ SHGLJUHHV RI DSSOLFDWLRQV WR VLQJOH PDLQ URWRU
KHOLFRSWHUV DQG KDYH QRZ EHHQ VXFFHVVIXOO\ DSSOLHG WR WKH
QRYHO KLQJHOHVV FRD[LDO SXVKHU FRQILJXUDWLRQ

%DVHG RQ WKH ZRUN SUHVHQWHG LQ WKLV SDSHU WKH IROORZLQJ

> [AS] Anonymous, "Aeronautical Design Standard (ADS-33) Performance Specification, Handling Qualities Requirements for Military Rotorcraft", US Army AMCOM, March

> [1] Johnson, *Helicopter Theory*, Dover Publications, Inc, New York, NY

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