Utilization of Wind Energy in Optimal Guidance Strategies VIDA Real- ime !onlinear "ontrol # et$odologies

A project present to
The Faculty of the Department of Aerospace Engineering
San Jose State University

in partial fulfillment of the requirements for the degree

By

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approved %y

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The Departmental Project Committee approves the Project Titled

Utilization of Wind En r!" in #$ti%al Guidan& Strat !i ' (ia R al)Ti% *onlin ar +ontrol M t,odolo!i '

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In t,i' a r1 a r al)ti% 1 on)5oard % t,odolo!" to utiliz 6ind n r!" a''o&iat d 6it, air &urr nt' i' roo' d for 'a(in! $o6 r1 %ini%izin! fu l &on'u%$tion and in&r a'in! nduran& durin! i!,t of an un%ann d a rial (,i&l 7UAV8 T, UAV i' %od l d a' a 3D d"na%i& $oint %a'' and a non)lin ar r & din! ,orizon &ontrol al!orit,% i' in('ti!at d for i%$l % ntation of r al)ti% !uidan& 'trat !i ' d (lo$ d for 6ind n r!" utilization9

I9 Introdu&tion

In 1203l t, Wri!,t 5rot, r' d %on'trat d $o6 r d air&raft i!,t for t, r't ti% in ,i'tor"9 In a littl o(r a ,undr d " ar' fro% t,at dat 1%an/ind ,a' !on fro% "in! $ri%iti(6ood n air&raft a f 6 ,undr d f t at a ti% to ' ndin! "in! % tal %ar(l' a&ro' ' t, $lan t9

W,il t, r ar %an" :a%$l ' of air&raft t,at ,a(!ro6n in 'iz and '&o$ o(r ,i'tor"1 t, r ar al'o :a%$l ' of air&raft t,at ,a(5 n '&al d do6n in 'iz 5ut 'till %aintain a %a''i('&o$ @ un%ann d a rial (,i&l '9 S%all)'&al un%ann d a rial (,i&l ' 7UAV'8 :i't in a (ari t" of for%' and ar u' d to ful ll a %ultitud of n d'9 A !lid r t,at a $ilot &ontrol' r %ot l"1 a dron t, %ilitar" u' ' for 'ur(illan& ar =u't t6o :a%$l ' of t, rol ' UAV' ta/ and t, n d' t, " ll9 Mor o(r1 UAV' ar u' d in a$$li&ation' for ' ar&, and r '&u 1 '&i n& 1 l i'ur 1 trainin!1 'ur(illan& 1 a!ri&ultur 1 %ilitar"1 r) !,tin!1 $oli&in! and %or 9

In ord r to ' r(t, ' a$$li&ation' a' 5 't a' $o''i5l 1 t, air&raft 6 &r at ar u'uall" o$ti%iz d 6it, r '$ &t to a d 'ir d $ rfor%an& o5= &ti(9 T, " ,a(!on fro% &o%$o'ition of 6ood to % tal and fro% % tal to &o%$o'it 9 T, " ,a(5 n r (i' d and r d 'i!n d 5a' d on ad(an& % nt' in t, or" and %$iri&al data9 Su&, ad(an& % nt' in&lud 6in!l t'1 6,i&, n,an& a rod"na%i& &i n&" and 'a(fu l 5" r du&in! t, do6n6a', indu& d on t, 6in!9 T, ir r & nt i%$l % ntation on &o%% r&ial airlin r' i' (id n& t,at air&raft inno(ation' ar not at an nd9 An o5' r(ation 6ort, notin! i' t,at t, 6a"' in 6,i&, air&raft ,a(i%$ro(d o(r

a5ilit" to &li%5 in altitud and %aintain l (l i!,t 6it, a$$in! 6in!' a' t, onl" % an' of roul'ion9 Anot, r 6a" in 6,i&, natur ,a' in u n& d our und r'tandin! of and a$$roa&, to i!,t i' t,rou!, tu5 r&l '1 t, 5u%$' on t, n' of Hu%$5a&/ 6,al '9 R ' ar&, ,a' found t,at tu5 r&l ' a&t a' (ort : ! n rator' to $rodu& tur5ul nt o6 o(r t, 6,al ' n and i%$ro('tall $ rfor%an& 9[2] Tu5 r&l ' ,a(5 n t 't d for a$$li&ation' in air 6it, r 'ult' indi&atin! n,an& % nt to lift ro rti '9[31 D] T, ' :a%$l ' of 5io%i%&r" ,ardl" '&rat&, t, 'urfa& of t, $ot ntial i%$ro(% nt' 6 &an ,arn '' fro% &o$"in! natur ' a$$roa&, to i!,t9

T, 6a"' natur a$$roa&, ' i!,t and t, 6a"' in 6,i&, 6 %i!,t 5 a5l to 5 n t fro% a 'i%ilar a$$roa&, ,a(5 n in('ti!at d in t, $a't9 Ri&,ard'on[5] &r at d a 'i%$l d"na%i&al %od l of 6ind)', ar 'oarin! and found t,at an 'ti%at d E0)20F of t, total n r!" r Buir d for 'u'tain d i!,t &an 5 :tra&t d fro% 6ind) ', ar 'oarin!9 T, $ro%i' of n r!" 5 n t' fro% d"na%i& 'oarin! %oti(at d ot, r r ' ar&, on t, to$i&9 G,ao[H] for%ulat d a !lid r' d"na%i& 'oarin! a' a 3D $oint %a'' 6it, utilization of 6ind !radi nt' a' a non) lin ar o$ti%al &ontrol $ro5l % and in('ti!at d (ariou' $ rfor%an& indi& ' and t r%inal &ondition' to "i ld di rin! o$ti%al i!,t $att rn'1 a&, 6it, t, ir o6n ro' &ti(u' '9 -urt, r%or 1 u'in! a 3D $oint %a'' and lin ar 6ind !radi nt'1 o$ti%al $o6 r d d"na%i& 'oarin! i!,t' of UAV' utilizin! 6ind !radi nt' at lo6 altitud ' for r du&in! fu l &on'u%$tion 6 r 'tudi d 5" l i and G,ao9[4] T, " 6 r a5l to &o%$ar t, &,ara&t ri'ti&' of %ini%u% t,ru't d"na%i& 'oarin! &a' ' 6it, t,o' of %ini%u% $o6 r d"na%i& 'oarin! to nd 'i%ilar fu l 'a(in!' 5 n t' 5 t6 n t, t6o a$$roa&, '9 Additional air &urr nt r ' ar&, of l i and G,ao[E] in&lud ' %od lin! a 2D $oint %a'' %od l of a UAV "in! t,rou!, a r !ion of (rti&all" o6in! t, r%al air &urr nt9 T, ir r 'ult' 'u!! 't 'i!ni &ant i%$ro(% nt' in UAV fu l &on'u%$tion ar $o''i5l 5" ta/in! ad(anta! of t, r%al air n r!"9 Enfor&in! t, &ti(n '' of u'in! t, r%al air &urr nt'1 A/,tar t al9[2] &r at d a $o'itionin! al!orit,% for autono%ou' t, r%al 'oarin! 6, r a 'i%ulat d HD#- %od l i' u' d to 'ti%at t, int ra&tion of a 'ail$lan 6it, t, r%al u$draft'9 In t, ir 'tud"1 a &ontrol '"'t %1 5a' d on &la''i&al t, or"1 i' u' d to !uid t, 'ail$lan for %a:i%u% 5 n t fro% t, t, r%al n r!"9 A 'ituationall" uniBu a$$roa&, to n r!" 'a(in!' i' ta/ n 5" W,it 1 +9 t al9[10] 6,o &ondu&t d a f a'i5ilit" 'tud" for %i&ro air (,i&l ' 7MAV'8 'a(in! n r!" 5" 'oarin! n ar tall 5uildin!'9 >ro(id d i''u ' of &ontrolla5ilit" &ould 5 o(r&o% 1 t, 'tud" ndin!' indi&at d t, ro' &t for 'oarin! to 5 r ali'ti&9 T, &urr nt 'tatu' of t, t &,nolo!" in t, ld of %iniatur air (,i&l ' and ro' &ti(futur inno(ation' 6 r di'&u'' d 5" G rd ' t al9[11] in a r (i 6 of %iniatur air (,i&l d 'i!n' 6it, 5ird)in'$ir d a$$in! 6in!'9

T, utilization of t, ' air &urr nt' and i!,t 'trat !i ' r Buir ' &o%$ut r al!orit,%' &a$a5l of $ro(idin! r al)ti% !uidan& 'olution'9 R & ntl"1 Gao1 J9)G91 t al9[12] roo' d a !uidan& 'trat !" for d"na%i& 'oarin! of UAV' t,at &ould r du& &o%$utational ti% to l '' t,an on $ r& nt of 6,at i' r Buir d 5" t, Gau'' $' udo) '$ &tral % t,od1 t, r 5" in&r a'in! t, $o''i5iliti ' for an on)5oard r al)ti% !uidan& 'trat !"9 >r (iou' 6or/

II9 Air&raft S"'t % D '&ri$tion

>ro$ rl" d nin! t, '"'t % at ,and i' &riti&al to ! n ratin! t, $ara% t r'1 Buation'1 and al!orit,% 'o t,at t, nal r 'ult' &an %ulat r alit" to t, d 'ir d l (l of a&&ura&"9 T, t"$i&al a$$roa&, to %od lin! t, air&raft d"na%i&' in&lud d nition of a '"'t % 6it, 'i: d !r ' of fr do% 7HD# -89 W,il t,i' i' &o%%on and ' r(' a' an a&&urat %od l1 t, &o%$utational 5urd n indu& d 5" t, ,i!,l" &o%$l : '"'t % %od l i' not id al for r al)ti% o$ti%ization a$$li&ation'9 -urt, r%or 1 t, a&&ura&"

6 , i& , &on ' i ' t ' of t , t r%inal &o ' t fun&tion and t , La ! ran ! ian9 It follo6 ' t , at t , n & ' ' ar" &ondition for o$ti%al &ontrol ta/ ' t , for% of t , t6o)$oint 5oundar" (alu $ro5l % ' , o6n in EB9714 89

$$
\begin{aligned}
& : K H^{T} K f \qquad 6 , r : 70; t8 K : 7t8 \\
& K H_{:}^{T} \qquad 6 , r 7T; t8 K \Updownarrow_{:}^{T} \\
& H_u K 0
\end{aligned}
\tag{7148}
$$

In EB9714 81 r $r ' nt ' t , &o ' tat (&tor and H i ' t , afor % ntion d Ha%iltonian a ' d n d 5"

$$
H K L L^{T} f \tag{71E8}
$$

Aa ' d on t , i ' a$$roa& , 1 t , &ontrol % t , odolo ! " i ' o5tain d a '

$$
u7t8 K ar ! f H_u \mathbb{M} : 7t8; 7t8; u7t8; \$7t8 \mathbb{N} K 0 ! \tag{7128}
$$

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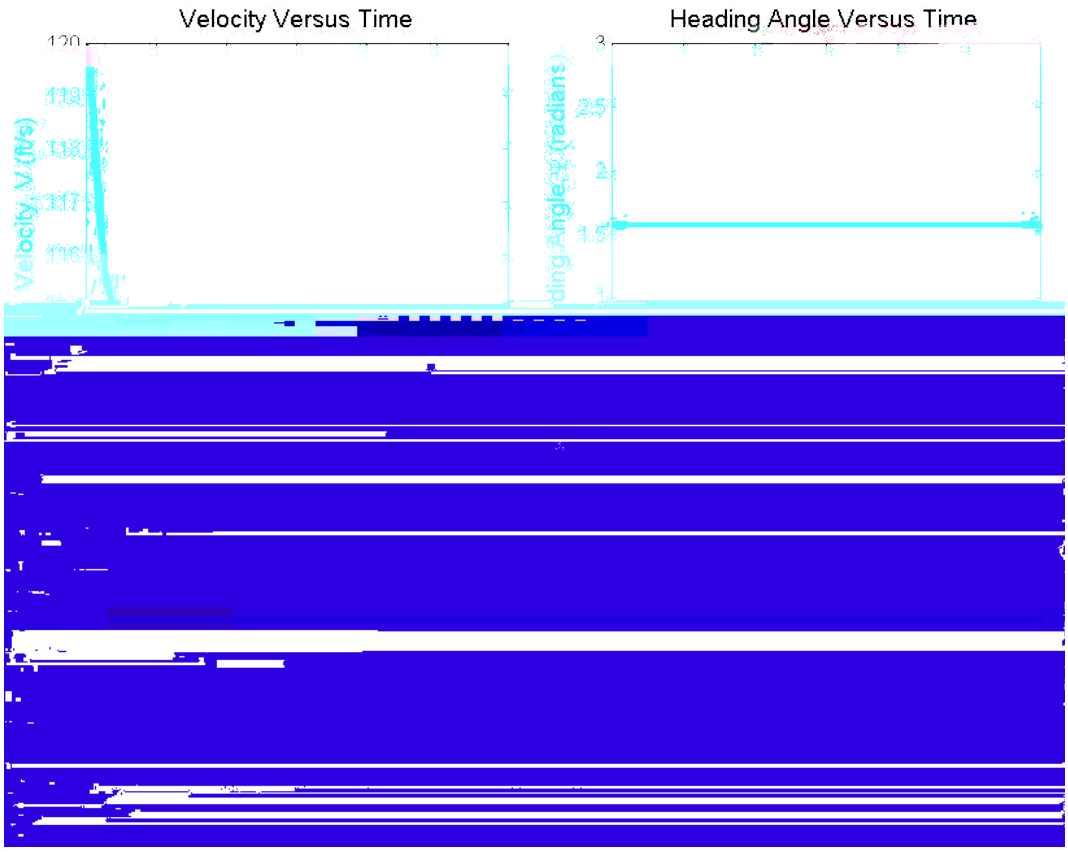

-i!ur 1⁹ V lo&it" V r'u' Ti%

A' &an 5 ' n fro% t, -i!ur)11 for t, i!,t '& nario 6, r t, 6ind '$ d i' d n d a' 20Mft⁹' &N 7Ea't81 air&raft i' a5l to %ini%iz it' air'$ d and t, r for r du& it' $o6 r &on'u%$tion1 t,rou!, EB⁹ 7E81 6,il 'till %aintainin! it' i!,t &our' 7i⁹ 9 : d, adin! an!l 89 T,i' d %on'trat ' t, a$$li&a5ilit" and 5 n t' of t, &on& $t for $o6 r %ini%ization in o$ti%al !uidan& 'trat !i ' in t, $r ' n& of 6ind⁹

VI⁹ +on&lu'ion

T,i' a r ,a' $r ' nt d an a$$roa&, for a UAV to ta/ ad(anta! of t, n r!" !ain' a(aila5l in "in! o$ti%al tra= &tori ' 6it, r '$ &t to &urr nt air &urr nt'⁹ Air&raft d"na%i&' ar %od l d 5" a 3D $oint %a'' %od l1 6, r &on'tant 6ind i' ta/ n into a&&ount for l (l i!,t &ondition'⁹ Wit, t, utilization of nonlin ar r & din! ,orizon &ontrol % t,odolo!" and in $r ' n& of fa(oura5l 6ind &ondition'1 6 d %on'trat d t, r du&tion in air'$ d1 6,i&, &orr '$ond' to %ini%iz d (alu of $o6 r1 t,u' fu l 'a(in!' t,rou!,out t, i!,t⁹ In futur 6or/1 t, a$$roa&, 'u!! 't d 6ill 5 :t nd d to in&lud t, ti% (ar"in! natur of t, 6ind⁹

R f r n& '

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