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Flight Measured Downwash of the QSRA

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SUMMARY

Several reports have been written on the performance of the Quiet Short-Haul Research Aircraft, which show the advantages of upper-surface blowing or the propulsive-lift wing as it applies to lift, maneuverability, and short takeoff and landing. This high lift generation at low speeds results in substantial downwash, especially in the low-aft fuselage tail position. The high T-tail of the Quiet Short-Haul Research Aircraft minimizes the undesirable downwash effects from the propulsive-lift wing. Queries from Department of Defense agencies and industry for quantitative values prompted a series of flight-measured downwash tests at the high T-tail and the low aft-fuselage position. The results are presented in a summarized format, showing downwash, $\Delta\varepsilon/\Delta\alpha$, for both locations. As would be expected, downwash increases for increased power and USB flap settings. The downwash is greater in the low aft-fuselage position as compared to the high T-tail area.

INTRODUCTION

The Quiet Short-Haul Research Aircraft (QSRA) is one of the many research aircraft at NASA Ames Research Center. When the upper-surface blowing (USB) project was originally conceived and initiated in 1974, the main objective was the proof-of-concept and development of a low-speed powered-lift data base, i.e., gathering performance and handling qualities data associated with takeoff and landing.

For this research work, a de Havilland C-8A Buffalo airframe modified with a propulsive-lift wing was chosen. The QSRA is powered by four Lycoming YF-102 turbofan engines (prototype to the ALF-502). The engines were configured over the wing to provide upper surface blowing (USB), a technique to develop high levels of lift at low noise levels. Figure 1 shows the salient features of the QSRA. A detailed description of the aircraft can be found in reference 1. The landing gear of the QSRA is fixed down since all the research goals are related to relatively low-speed flight. The beneficial effect of USB on takeoff and landing performance as compared to conventional takeoff and landing (CTOL) aircraft was thoroughly investigated in a series of experiments (refs. 2, 3, and 4). These experiments show that landings and takeoffs can be consistently accomplished in 700 and 800 ft, respectively, with no headwind.

Because of the high levels of wing powered lift, downwash becomes a major consideration in the design of tail control surfaces. The objectives of the downwash experiments were 1) to satisfy the inquiries from DoD and industry concerning the downwash in the aft-fuselage area as it may affect the feasibility and requirements of a low-tail design, 2) to compare flight-data results of the downwash in the

T-tail area with wind-tunnel data, and 3) to provide a downwash data base for two tail locations to allow limited interpolation of downwash characteristics for a wide variety of horizontal tail locations for future aircraft design.

SYMBOLS

i	= angle of incidence; angle formed by zero lift chord and the longitudinal axis
α_{aw}	= angle of attack of the wing = $\alpha_{\tau} + i_w$
α_{TRUE}	= TRUE angle of attack = $\theta - \gamma$
ε	= downwash angle; difference between angle of attack at the wing and angle of attack at the tail
γ	= flightpath of aircraft relative to the horizon. Gamma = arcsin $(\dot{h}_T/1.688V_T)$
θ	= aircraft (gyro) pitch attitude relative to the horizon
θ_p	= angle as measured from the longitudinal axis of the downwash measurement probe to the relative wind

Subscripts

a	= absolute
p	= probe
t	= tail
T	= true
w	= wing

TECHNICAL APPROACH AND PROCEDURES

The rake, an aerodynamically designed structure mounted to the aircraft aft-fuselage which held 6 probes to measure the movement of air, is shown in figures 2(a) and 2(b).

Figures 3(a) and 3(b) show the probes in the T-tail position.

The first downwash experiment was the aft-fuselage measurements. The downwash tests were made at a nominal altitude of 8,000 ft, and a series of 18 alpha (angle-of-attack) sweeps were made.

The second experiment was to measure the downwash characteristics forward of the horizontal tail. This second experiment required a minimum of three flights because at the time of the second experiment, only three probes were available. The other three pressure probes were destroyed in a wind-tunnel mishap. Because of this situation, the following test procedure was devised so that the probe at position #1, inboard, would not be moved and would provide a flight-to-flight correlation of the results.

RESULTS AND DISCUSSION

The parameters of prime concern of this report are downwash (ε) and wing alpha (α_{aw}). Sidewash angles and local dynamic pressures were also measured but are not addressed in this report.

Low Tail/Aft-Fuselage Location

Figure 4 shows downwash versus wing alpha for constant thrust (89% fan rpm) as the USB flap positions are varied. The results show greater values of downwash as the USB flap settings are increased from 0° to 60°. Also, the $\Delta\varepsilon/\Delta\alpha_{aw}$ slopes increase from 0.75 to 1.04 as USB flap setting is increased from 0° to 60°. As the USB flap setting increases there is a well defined difference in the downwash behind the inboard and outboard engines. At 60° USB flap, the downwash behind the inboard engine is 4-5° more than that behind the outboard engine.

Important information gained during this test includes the slope of $\Delta\varepsilon/\Delta\alpha_{aw}$ for the various conditions and the variation of slope with varying thrust or USB flap settings. Table 1 shows a matrix of conditions arranged with increasing thrust horizontally and increasing USB vertically. It can be seen that the greatest $\Delta\varepsilon/\Delta\alpha_{aw}$ slope is at maximum thrust (89% fan rpm) and 60° USB flap setting, the condition for the highest levels of wing powered lift. At a constant thrust corresponding to 89% fan rpm, the range of $\Delta\varepsilon/\Delta\alpha$ with increasing USB flap setting is from 0.75 (0° USB flap) to 1.04 (60° USB flap). For a constant 60° USB flap setting, power increases from 70% to 89% fan rpm cause an increase in $\Delta\varepsilon/\Delta\alpha_{aw}$ from 0.88 to 1.04. The typical QSRA takeoff and landing approach conditions are highlighted in table 1. Table 2 shows the relationship between thrust and percent fan.

T-Tail

The T-tail downwash experiment consisted of three separate flights because of the availability of only three pressure probes. For this reason, it was important to investigate the flight-to-flight correlation of data using a common probe position. Figure 5 shows correlation of downwash for two conditions: USB = 0°, fan at 60%, and USB = 50°, fan at 89%.

Figure 6 shows the spanwise T-tail downwash variation at constant 89% fan rpm settings with increasing USB flap settings for all 6 probe positions. The downwash increases with USB flap setting, as in the low-tail position (fig. 4). However, the downwash magnitudes and the $\Delta\varepsilon/\Delta\alpha_{aw}$ slopes are less at the T-tail location. Also, the distinct inboard/outboard downwash magnitude difference seen at large USB flap settings at the low-tail position are not evident at the T-tail.

Table 3 shows a matrix of $\Delta\varepsilon/\Delta\alpha_{aw}$ slopes for the tested conditions arranged with increasing thrust settings horizontally and increasing USB flap settings vertically. The largest $\Delta\varepsilon/\Delta\alpha_{aw}$ slope changes are found at 89% fan with increasing USB flap setting with $\Delta\varepsilon/\Delta\alpha_{aw}$ varying from 0.45 to 0.78. The corresponding low-tail downwash slopes (table 1) are approximately 1.5 times greater than those at the T-tail (table 3) for 89% fan with varying USB flap setting.

Figure 7, a three-dimensional (3-D) plot of the downwash data obtained in both experiments, depicts a sheet of air as experienced by the T-tail and low-tail probes for the QSRA landing approach configuration (50° USB flap, 59° DSF and AEO at 70% fan rpm). The 3-D data plot format shows the relatively consistent spanwise characteristics of the downwash fields with all engines operating. The magnitude of the downwash is greater at the low-tail position as is the downwash slope, $\Delta\varepsilon/\Delta\alpha_{aw}$, 0.85 to 0.5.

CONCLUSIONS

1. The downwash angle increases with increasing USB flap setting and thrust, the two predominate wing lift increasers. The largest downwash occurs with maximum USB flap setting and thrust.

2. The downwash slopes, $\Delta\varepsilon/\Delta\alpha_{aw}$, also increase with USB flap setting and thrust increases. There is also a tendency for slope increases as wing alpha increases.

3. The downwash slope, $\Delta\varepsilon/\Delta\alpha_{aw}$, at the low-tail position is about 1.5 to 2 times the value of that at the high T-tail position. This means that the low-tail position provides less stability than the high T-tail position. This would increase the need for a stability augmentation system (SAS) for a low-tail configuration. The trim changes would also be higher at the low-tail position increasing the need for a variable incidence horizontal stabilizer at the low-tail position. Automatic trim may be required as USB flap setting and thrust are increased on a low-tail configuration.

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Table 1. Low tail position downwash $\Delta\varepsilon / \Delta\alpha_{aw}$ slopes

Thrust (AEO) / Flaps	60% fan rpm	70% fan rpm	80% fan rpm	89% fan rpm
	$\Delta\varepsilon / \Delta\alpha_{aw}$	$\Delta\varepsilon / \Delta\alpha_{aw}$	$\Delta\varepsilon / \Delta\alpha_{aw}$	$\Delta\varepsilon / \Delta\alpha_{aw}$
USB-0° DSF-0°	0.71 to 0.82		0.82	
USB-0° DSF-59°	0.68 to 0.77	0.74	No data	Takeoff 0.75 Config
USB-30° DSF-59°	...	0.77	0.85	0.85
USB-50° DSF-59°	...	Approach 0.85 Config	0.92	1.02
USB-60° DSF-59°		0.88	0.94 to 1.0	1.04

	Cond	USB (deg)	FAN (%)	DSF (deg)	$\Delta\varepsilon / \Delta\alpha_{aw}$
#3 eng idle	17	50	80	59	0.88
#4 eng idle	18	50	80	59	0.916-1.1

Table 2. Thrust/engine fan rpm relationship.

FAN, %	THRUST, lb	THRUST, %	4 ENGINE THRUST, lb
-89	5900	100	23600
85	5300	90	21200
-80	4500	76	18000
75	3800	64	15200
-70	3300	56	13200
65	2700	46	10800
-60	2400	40	9600
55	2000	34	8000
50	1700	29	6800

NOTE: DUE TO TEMPERATURE LIMITATIONS THE MAXIMUM THRUST IS AT 89% FAN RPM INSTEAD OF THE USUAL 100%.

Table 3. T-tail position downwash $\Delta\varepsilon / \Delta\alpha_{aw}$ slopes

Thrust (AEO) / Flaps	60% fan rpm	70% fan rpm	80% fan rpm	89% fan rpm
	$\Delta\varepsilon / \Delta\alpha_{aw}$	$\Delta\varepsilon / \Delta\alpha_{aw}$	$\Delta\varepsilon / \Delta\alpha_{aw}$	$\Delta\varepsilon / \Delta\alpha_{aw}$
USB-0° DSF-0°	0.34		0.4	
USB-0° DSF-59°	0.34	0.31	0.42	Takeoff 0.45 Config
USB-30° DSF-59°	...	0.38	0.54	0.57
USB-50° DSF-50°	...	Approach 0.5 Config	0.51 to 0.71	0.78

	Cond	USB (deg)	FAN (%)	DSF (deg)	$\Delta\varepsilon / \Delta\alpha_{aw}$
#3 eng idle	13	50	80	59	0.42
#4 eng idle	14	50	80	59	0.61

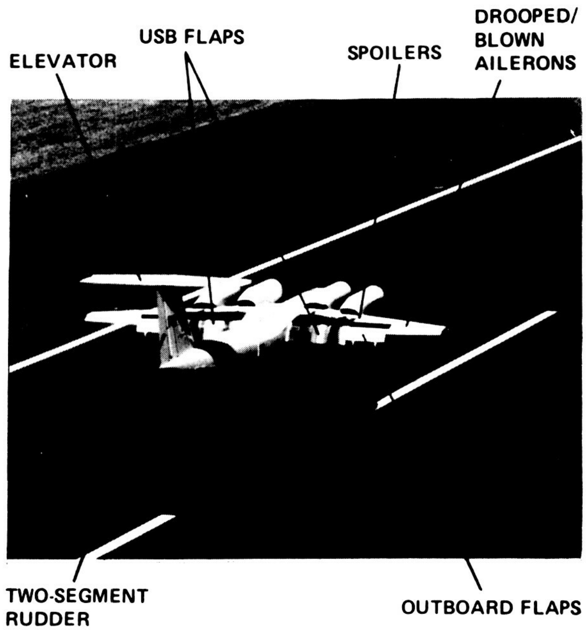

Figure 1.- QSRA with control surfaces identified.

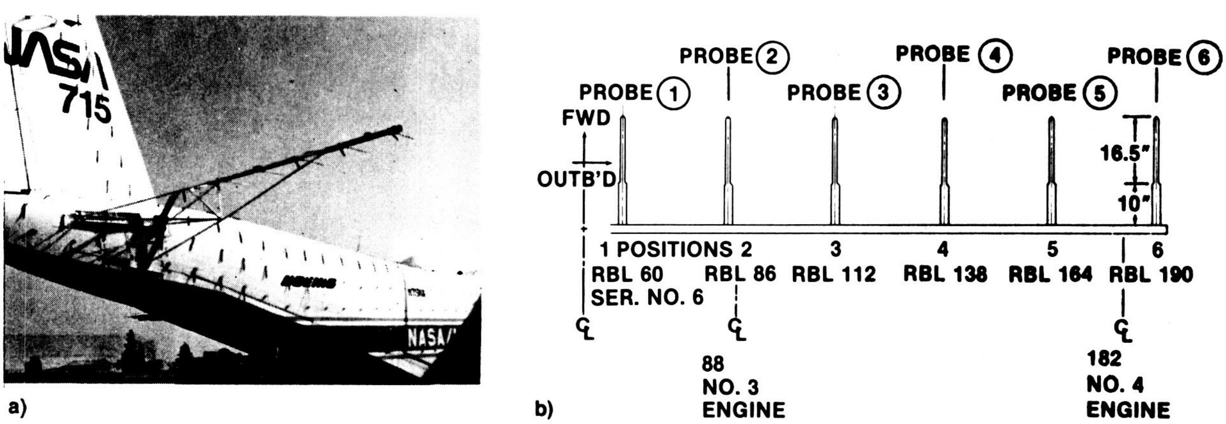

Figure 2.- QSRA low-tail downwash rake and probes. a) Aircraft location; b) plan view.

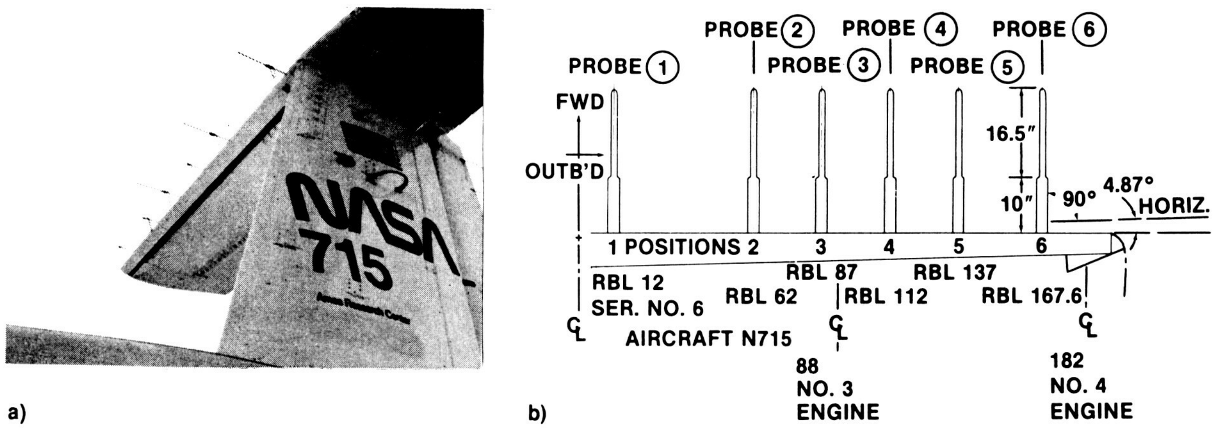

Figure 3.- QSRA T-tail downwash rake and probes. a) Aircraft location; b) plan view.

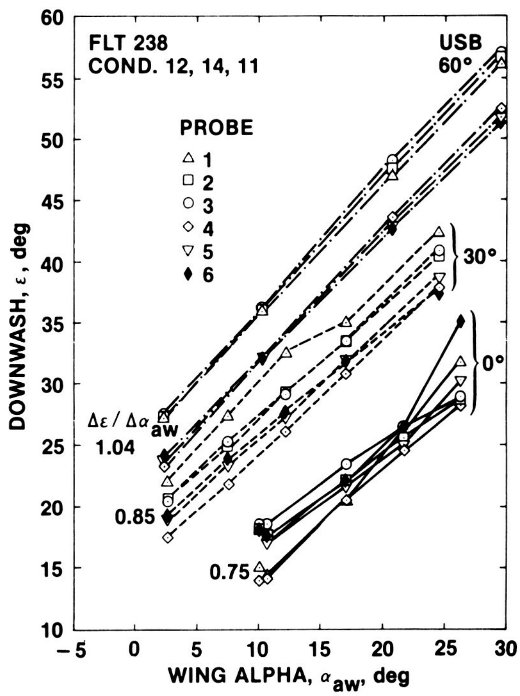

Figure 4.- Low-tail downwash variation with wing alpha and USB flap setting at 89% fan rpm and 59° DSF.

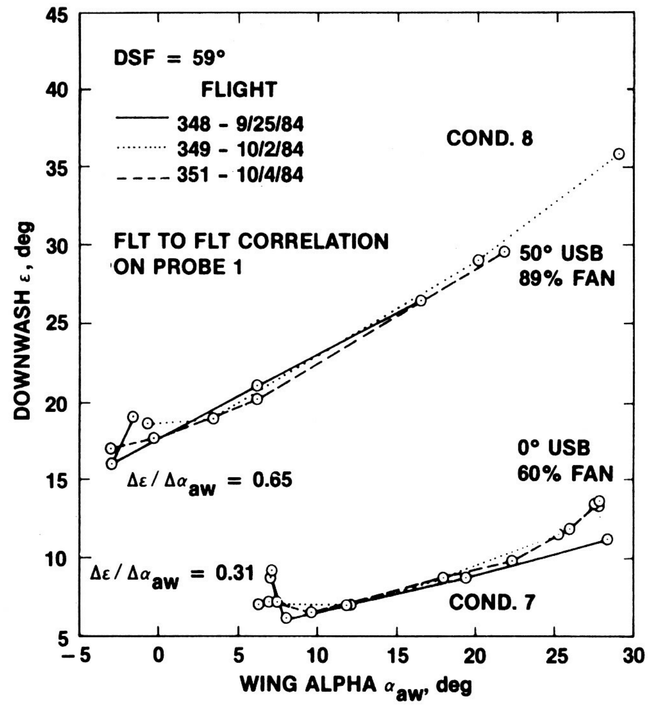

Figure 5.- Flight-to-flight data correlation of T-tail downwash probe 1, fan at 60%, USB flap at 0° and fan at 89%, USB flap at 50°.

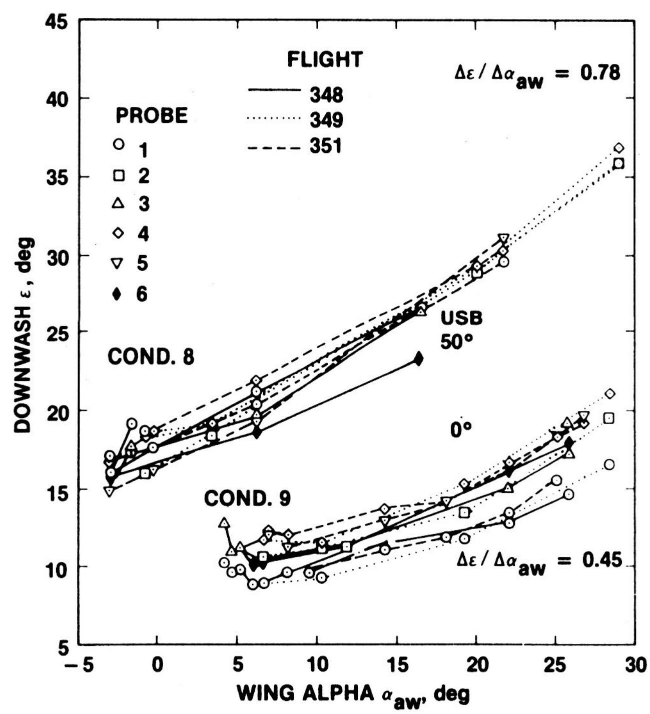

Figure 6.- T-tail downwash variation with wing alpha and USB flap setting at 89% fan rpm and 59° DSF.

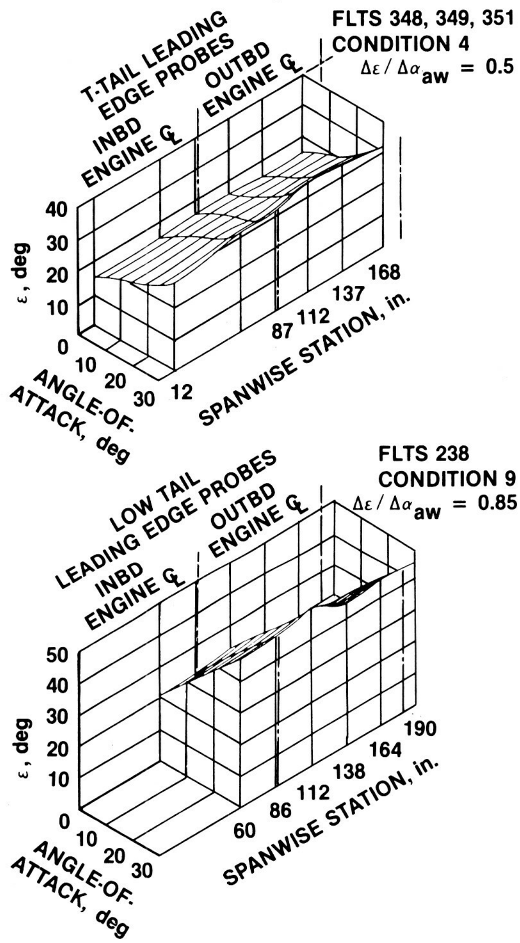

Figure 7.- Spanwise downwash comparison of low and T-tail positions for the QSRA landing configuration: AEO at 70% fan rpm, 50° USB, and 59° DSF.

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16. Abstract

Several reports have been written on the performance of the Quiet Short-Haul Research Aircraft, which show the advantages of upper-surface blowing or the propulsive-lift wing as it applies to lift, maneuverability, and short takeoff and landing. This high lift generation at low speeds results in substantial downwash, especially in the low-aft fuselage tail position. The high T-tail of the Quiet Short-Haul Research Aircraft minimizes the undesirable downwash effects from the propulsive-lift wing. Queries from Department of Defense agencies and industry for quantitative values prompted a series of flight-measured downwash tests at the high T-tail and the low aft-fuselage position. The results are presented in a summarized format, showing downwash, $\Delta\varepsilon/\Delta a$, for both locations. As would be expected, downwash increases for increased power and USB flap settings. The downwash is greater in the low aft-fuselage position as compared to the high T-tail area.

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