Flight Test of the Japanese Upper Surface Blowing STOL Experimental Aircraft ASKA

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The Upper Surface Blowing STOL aircraft named ASKA was developed and flight tested by the National Aerospace Laboratory of Japan between 1977–1989. The aircraft was a conversion of the Kawasaki C-1 medium transport, with four newly developed FJR710/600S turbofan engines on the wing. The short takeoff and landing performance, including the stability and control augmentation system and boundary-layer control, was intensively examined by the flight test. Flight-test data were obtained at altitude and converted to the standard sea level conditions to compare with the design data. From the viewpoint of the lift-and-drag and related performances, the design STOL capability was proven by the flight-test program.

Nomenclature

AIL. = aileron
ALT = altitude
CAS = calibrated airspeed
C_j = gross thrust coefficient
C_L = lift coefficient
C_D = drag coefficient
C_{Da} = aerodynamic drag coefficient
EAS = equivalent airspeed
G/A = go-around
L/E = leading edge
L/D = lift-to-drag ratio or landing
MAC = mean aerodynamic center
$N1$ = engine fan rating
OAT = outside air temperature
O/B = outboard
Q = pitch rate
S/L = sea level
T/O = takeoff
t/c = thickness to chord ratio
W/O = washout
δ = deflection
γ = flight path angle
θ = pitch attitude

Subscripts

c = command
DLC = direct lift control
e = elevator
$-r$ = right-hand side
SP = spoiler
TH = throttle lever

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Introduction

IN Japan, there are many airfields that cannot accept large jet aircraft; therefore, a short takeoff and landing capability is most desirable for Japanese domestic aviation. The National Aerospace Laboratory (NAL) of Japan started working on the upper surface blowing (USB) STOL aircraft program in 1977.[1] This work included airframe design, engine development, and a flight program to evaluate how well the USB STOL system functioned. The experimental aircraft ASKA was built based on the Kawasaki C-1 medium transport design, with four newly developed turbofan engines mounted on the wing, as shown in Fig. 1. The ASKA made its first flight in October 1985. The flight test consisted of about 100 flights between then and March 1989.

Two years prior to the ASKA program, NASA commenced the Quiet Short-Haul Research Aircraft (QSRA) program at Ames Research Center for the USB flight research.[2] This program provided a broad range of flight data. The ASKA is bigger in size than QSRA and has a better high-speed capability, as it is a conversion of the turbo jet aircraft. There was cooperation between NASA Ames Research Center and NAL in the sharing of research data.

A considerable amount of research work was done in the design phase. In the flight phase, the low-speed performance of the aircraft was examined intensively through step-by-step

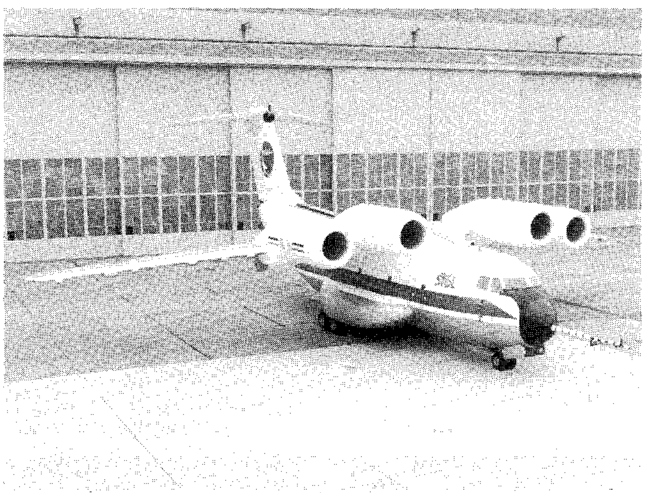


Fig. 1 Photograph of the ASKA.

AERODYNAMIC DATA	WING	HORZ	VERT
AREA (TRAP), m^2	120.5	30.1	22.8
SPAN, m	30.6	11.3	5.1
ASPECT RATIO	7.77	4.90	1.14
SWEEP (25% $\bar{C}$), deg	20.0	25.0	30.0
t/c AT ROOT, %	12.0	12.0	12.0
t/c AT TIP, %	11.0	10.0	12.0
INCIDENCE, deg	4.0	–	–
DIHEDRAL, deg	-5.5	-5.0	–
TAIL ARM, m	–	15.7	13.1

WING M.A.C. = 4.434 m

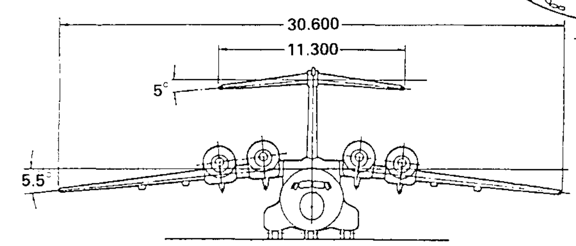
CONTROL SURFACES	AREA, m^2	BLOWN
AILERON	4.76	BLC
USB FLAP	12.7	USB
OUTBOARD FLAP	10.6	NONE
L.E. SLAT	9.2	BLC
SPOILERS	4.3	NONE
ELEVATORS	7.6	NONE
RUDDERS	6.9	NONE

PROPULSION	
ENGINE	FJR 710/600S
STATIC THRUST	4,300 kg*
BYPASS RATIO	6.0

*CURRENT LIMIT, DESIGN THRUST = 4,800 kg

PERFORMANCE:

APPROACH SPEED	72 knots
APPROACH PATH ANGLE	-6°
TAKE-OFF DISTANCE	680 m TO 35 ft ALT.
LANDING DISTANCE	480 m FROM 35 ft ALT.
MAXIMUM SPEED	0.565 M AT 20,000 ft, 38,700 kg



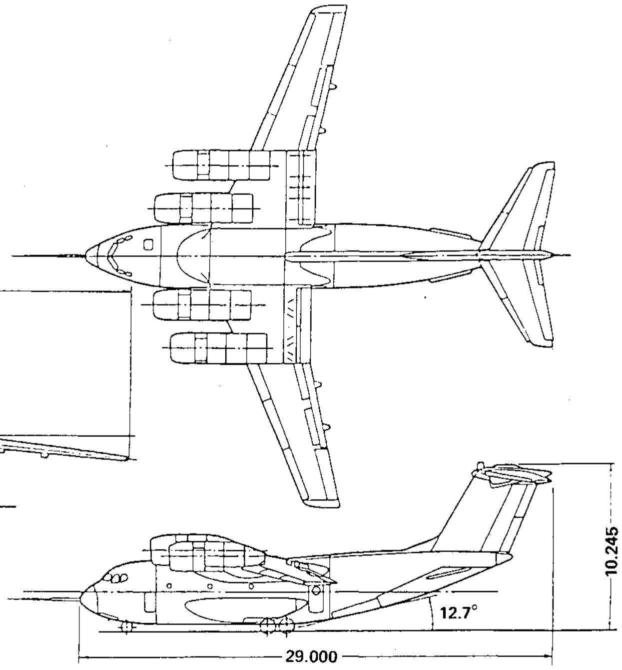


Fig. 2 Three views and dimensional details of the ASKA.

extension of the flight envelope from higher to lower speed conditions. The lift-and-drag performance during takeoff and landing was examined primarily at altitudes of 5000 to 10,000 ft above sea level. Flight data were converted to the standard sea level condition to estimate the actual STOL performance.

In addition to the USB configuration, the stability and control augmentation system (SCAS) and the boundary-layer control (BLC) were considered essential to fly at very low speed. Among SCAS modes, the flight path control (FPC) is designed to control the flight path with one handle. The BLC is equipped with ailerons and leading edges of the outboard wing. It was found very difficult to determine the required quantity of bleed air for the BLC with use of the model test. The effectiveness of the system was also flight tested.

Discussions in this paper, based on the flight data, clarify the effectiveness of SCAS and BLC and USB STOL performance of the aircraft to prove the design.

Program Overview

NAL has been doing fundamental research on the short takeoff and landing aircraft for many years. After evaluation of concepts for the STOL aircraft, NAL determined that the USB system was the most feasible and started the experimental aircraft ASKA program in 1977. The Kawasaki C-1 medium transport was selected for the base aircraft; the contractor's design team worked in the Gifu Works of Kawasaki Heavy Industries. As the ASKA is the first four-jet-engined aircraft developed in Japan, the program, in addition to being a STOL research program, is also one of the Japanese aircraft industry's biggest projects.

In 1979, the basic design was finished with manufacturing and assembly completed by March 1985. Ground testing followed, and the ASKA made its first flight in October 1985.

As for the engine, NAL has developed JR and FJR series research engines. NAL decided to install the FJR710/600S turbofan engine on the ASKA.[3-5] The base engine was developed with funding from the Ministry of International Trade and Industry, and the modification program was carried out as a part of the ASKA program to make the engine airworthy.

Ground testing included wind tunnels,[6,7] simulators,[8-11] and a control system mock-up,[12] primarily to confirm the low-speed performance during the design and manufacturing.

A new flight-test center was built and equipped at Gifu Airfield near Nagoya for the flight test,[13-15] which was made between October 1985 and March 1989.

The flight-test program was divided into two phases.[16-18] Phase 1 was from first flight until first actual STOL configuration landing in March 1988. The basic airworthiness and STOL performance were examined at altitude, and takeoff and landing were made using the shallower flap CTOL configuration. Phase 1 was finalized by the actual STOL landing. The phase 2 flight-test (March 1988–March 1989) covered intensive research on the STOL performance and operation. Approximately 100 flights were made during the 3½-yr flight-test term, providing various kinds of data on the USB STOL aircraft.

In addition to the USB flight test, NAL conducted research on the high-speed performance of the ASKA. The numerical simulation of high-speed flow around the complete configuration of the ASKA was accomplished.[19,20] High-speed wind-

CONFIGURATION	FLAPS, deg		SLAT, deg	BLC		DESIGN WEIGHT
	USB	O/B		L.E.	FLAPERON	
CLEAN	0	0	0	OFF	OFF	38,700 kg
CTOL	15	25	25	OFF	OFF	45,000 kg (T/O) 36,860 kg (L/D)
STOL TAKE-OFF	20	30	25	OFF	ON	38,700 kg
STOL LANDING	40	65	40	ON	ON	36,860 kg
STOL GO-AROUND	20	65	25	OFF	ON	36,860 kg

Fig. 3 Configurations and weights.

tunnel testing was conducted as a part of the NASA-Ames and NAL joint research program.[21,22] Numerical and experimental results were obtained and compared to determine the high-speed performance of the ASKA. Pilot interchange was also a part of the NASA-Ames and NAL joint program; two QSRA pilots and two engineers flew ASKA to evaluate the aircraft in November 1988.

The ASKA program ended in March 1989; however, laboratory and flight-test data are still being evaluated for publication.

Description of the ASKA

ASKA and FJR710/600S

Three views and the STOL design are shown in Fig. 2. The ASKA's key STOL performance is 72 kt and -6 deg flight path angle at approach, with 36,800 kg landing weight. The ASKA is a conversion of the Kawasaki C-1 transport. Four newly developed FJR710/600S engines are mounted on the wing to form the USB configuration. Inboard spoilers are removed and inboard flaps are replaced by the USB flap. The inverted camber slat was equipped in the horizontal tail to avoid stalling at the tail's lower surface. Elevators, ailerons, and a rudder were extended in chord. A droop system was added to ailerons to augment the lateral control power in low-speed flight.

The maximum designed static thrust for the FJR710/600S turbofan engine was 4800 kg; however, the thrust was limited to 4300 kg throughout the flight phase due to the lack of endurance testing at maximum rating.

The ASKA's design configurations and weights are tabulated in Fig. 3. In addition to three STOL configurations, the ASKA has the CTOL configuration. With the CTOL configuration, the ASKA can take off at a heavier weight, resulting in a longer flight test at altitude.

Boundary-Layer Control and the Stability and Control Augmentation System

In addition to the USB configuration, the ASKA has some design features, as shown in Fig. 4. The most important systems supporting the USB configuration are the BLC and SCAS.

Boundary-Layer Control

The BLC is employed at leading edges of the outboard wing and ailerons. The BLC combinations are also shown in Fig. 3. The cross bleeding from engines on one wing to the BLC on the opposite wing allows for asymmetrically operating engine situations.

Stability and Control Augmentation System

The SCAS is used to improve low-speed flying qualities. The system is triplex, and centered by digital computers. The SCAS consists of 10 modes, that is, pitch rate/attitude control wheel steering (CWS), flight path control (FPC), speed hold, auto trim, STOL go-around, roll CWS, engine failure com-

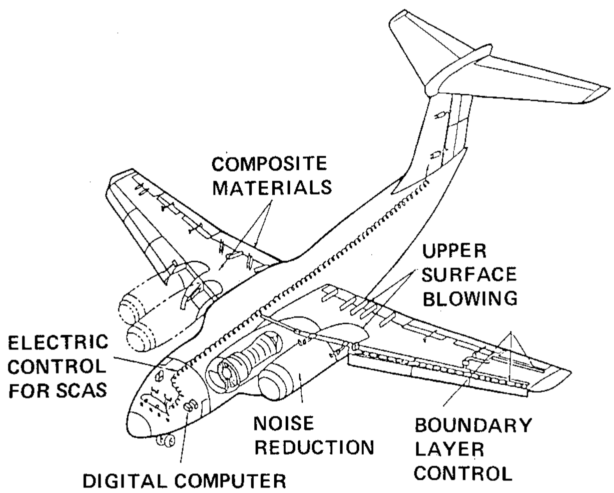


Fig. 4 Schematic of the major technologies in the ASKA.

pensation (EFC), β-command, and CTOL yaw damper. Among these modes, the most characteristic of the STOL low-speed operations is FPC. The FPC is an open-loop control of the flight path by the engine power and spoilers, as shown in Fig. 5. The FPC lever is connected to engines and spoilers via the control computer. In the case of the powered-lift aircraft, the flight path can be controlled by the engine power. However, engines have a time constant of a couple of seconds and the spoiler is very effectively used back and forth around the uprig position to achieve a quick change in lift. Spoilers are used through the washout, which is of the same time constant as the engine.

Flight-Test Results

Flight Results and Design Data

Flight-test results are chiefly obtained by the quasisteady angle-of-attack sweep test at altitude. The aircraft was stabilized at the initial speed, and the airspeed reduced very slowly by increasing the angle of attack, leaving the engine rating constant. The design data are chiefly obtained by the wind-tunnel testing using the 8% full span model with turbine simulator engines on it. The 8% model may be too small to identify the low-speed performance. Even if gross thrust coefficients coincide, the flowfield cannot be simulated due to the difference in the Reynolds number, exhaust gas speed, and so forth. For the design of the BLC, the bigger wing model was used for the wind-tunnel testing for the sake of the Reynolds number.

Airspeed vs Flight Path Angle Diagram

The low-speed operational capability of the powered lift aircraft can be observed very clearly in the speed vs flight path

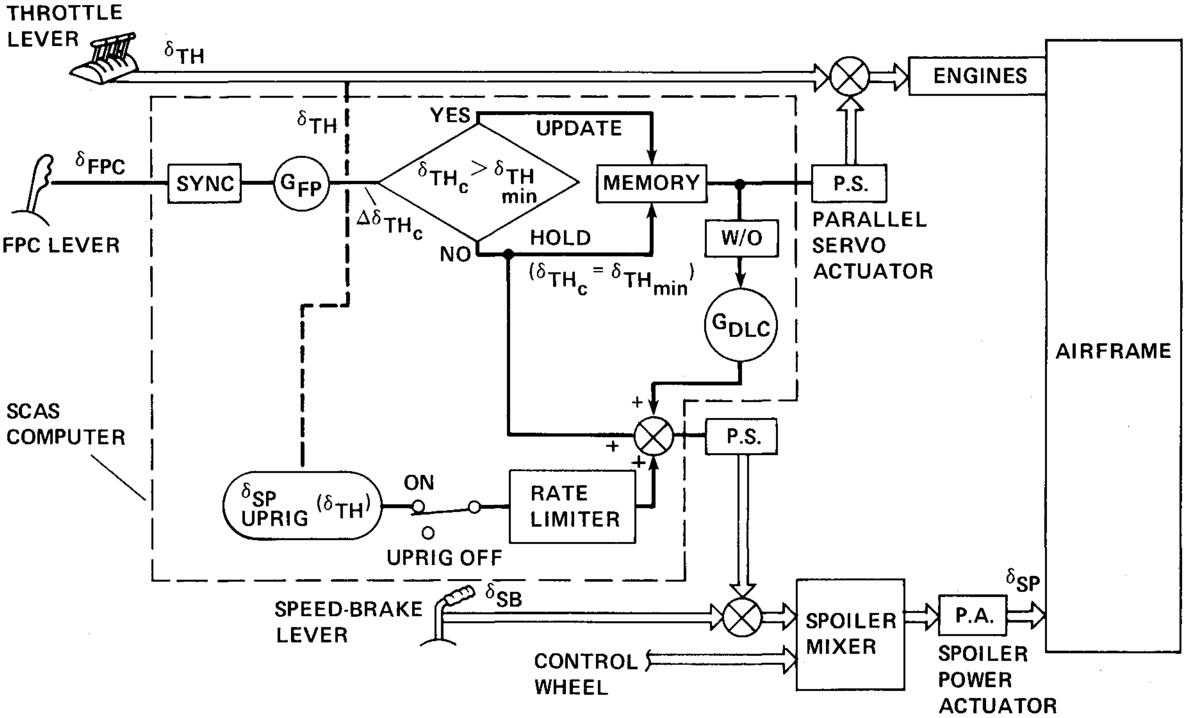
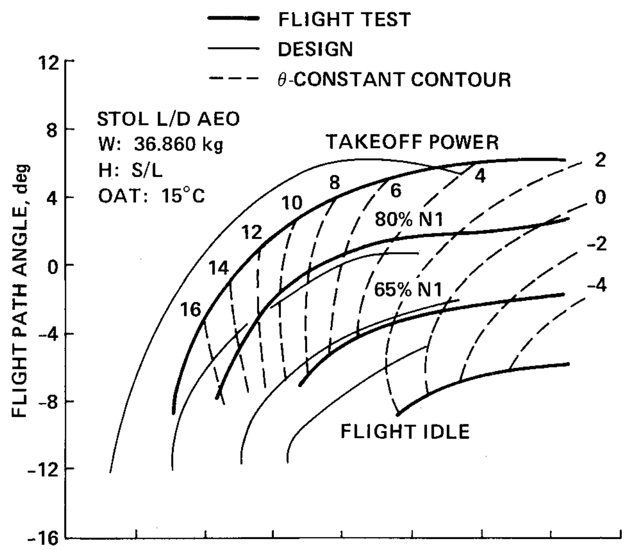
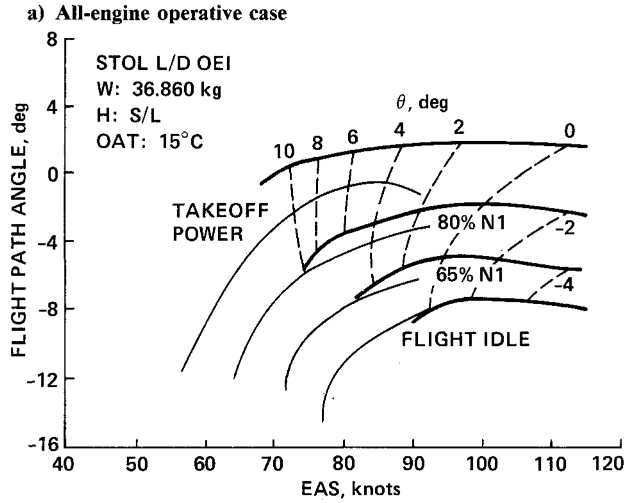


Fig. 5 SCAS flight path control diagram.

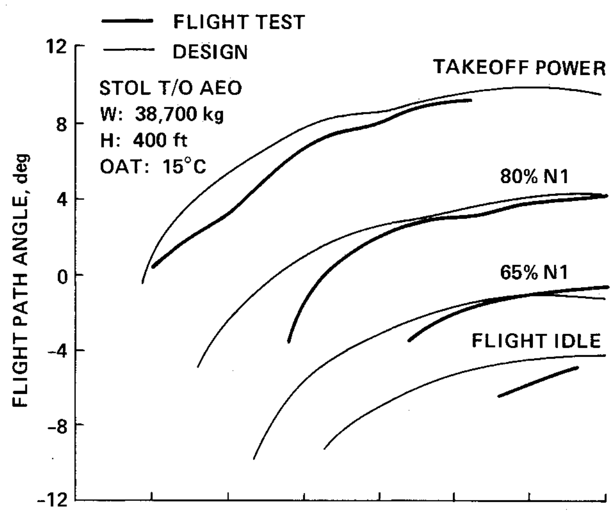


a) All-engine operative case

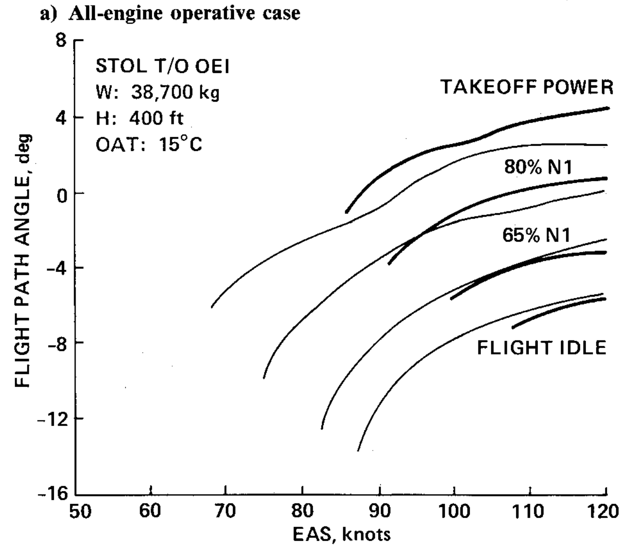


b) Outboard engine inoperative case

Fig. 6 V-γ diagram : STOL landing configuration.



a) All-engine operative case



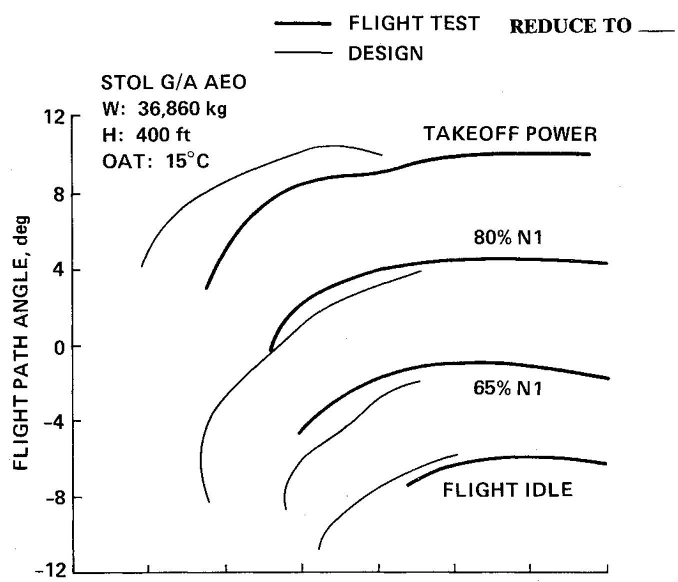
b) Outboard engine inoperative case

Fig. 7 V-γ diagram : STOL takeoff configuration.

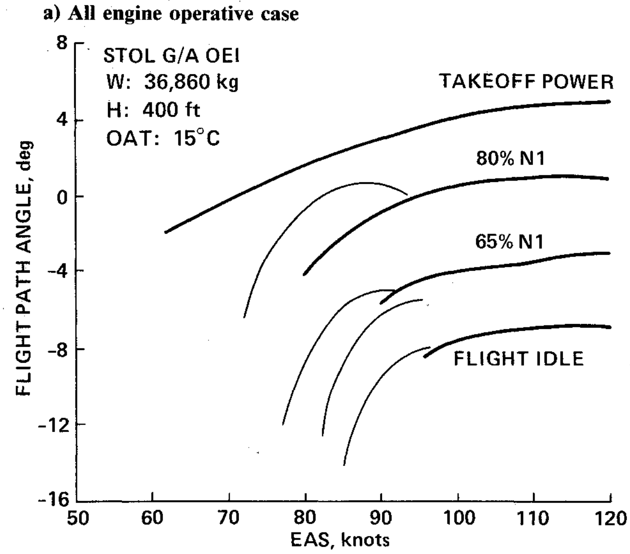
angle, namely the V-γ diagram. Figures 6–8 show the flight-tested V-γ diagram compared with the design data. Configurations are STOL landing, STOL takeoff, and go-around, respectively. All-engine operative (AEO) cases are in part a of the figures, and outboard engine inoperative (OEI) cases are in part b of the figures. The one engine inoperative performance is a fundamental concern from the viewpoint of airworthiness criteria. The OEI cases were examined intensively, for they are considered more critical than inboard engine inoperative cases. The characteristics of V-γ vary according to the engine rating, indicated by the fan rating $N1$. For example, 80% $N1$ stands for 80% of the maximum fan rating in the figures.

Flight-test results are obtained at altitudes and converted to the standard sea level condition. The method of conversion used here was proposed by Stevens.[23] The ram drag is basically linear to airspeed, and can be obtained from the engine chart if flight conditions such as the Mach number and engine rating are specified. The total drag obtained by the flight test at altitudes is subtracted by the ram drag by data in the engine chart. The resultant drag is called the aerodynamic drag and can be normalized by the dynamic pressure and the wing area. Standard sea level performance can be obtained by using this normalized aerodynamic drag and the ram drag at sea level found in engine charts.

In AEO cases, the flight results are in fairly good accordance with the design data, whereas, in OEI cases, the flight test results show better climb capability. Note especially that the STOL landing configuration has the climbing capability in the OEI case, as shown in Fig. 6b, that would not be expected from the results of the design wind-tunnel testing. In flight-

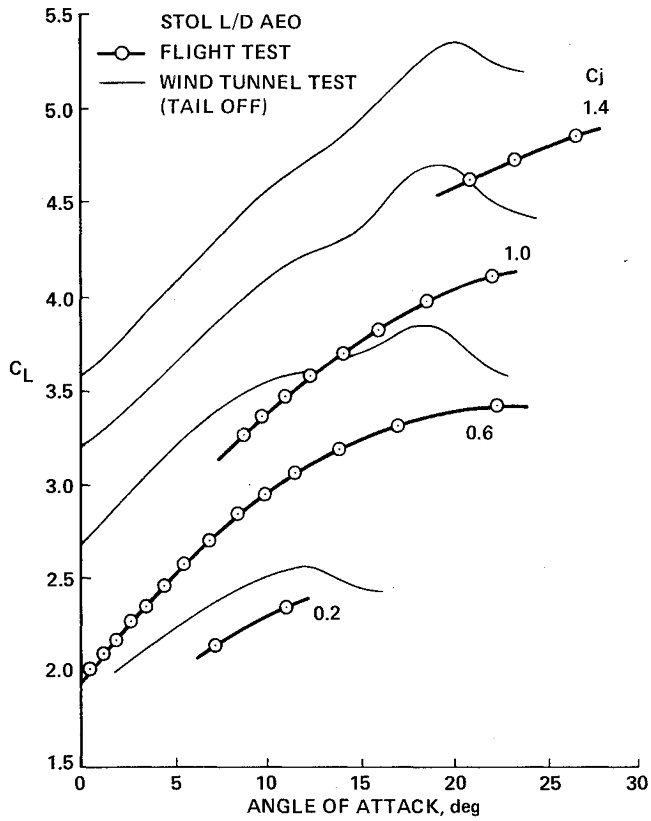


a) All engine operative case

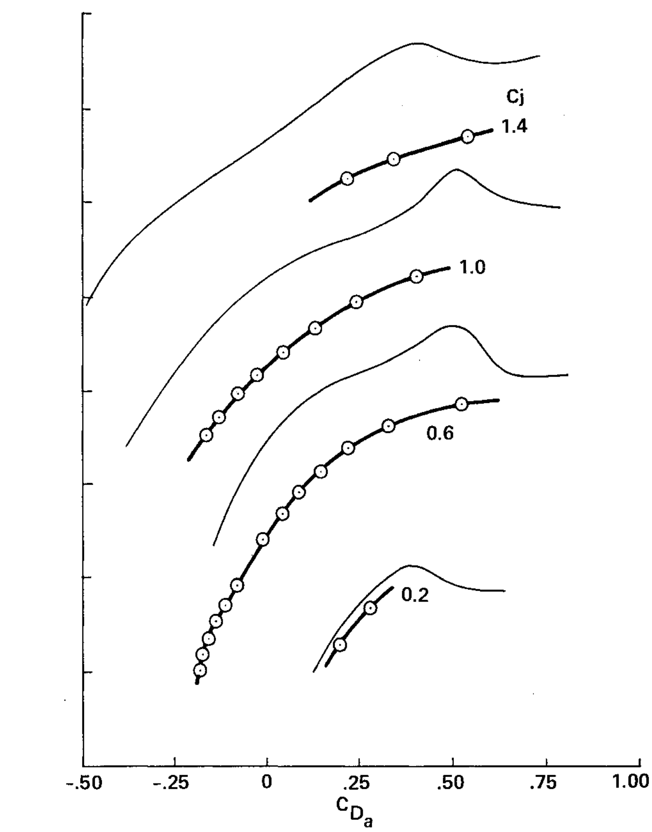


b) Outboard engine inoperative case

Fig. 8 V-γ diagram : STOL go-around configuration.

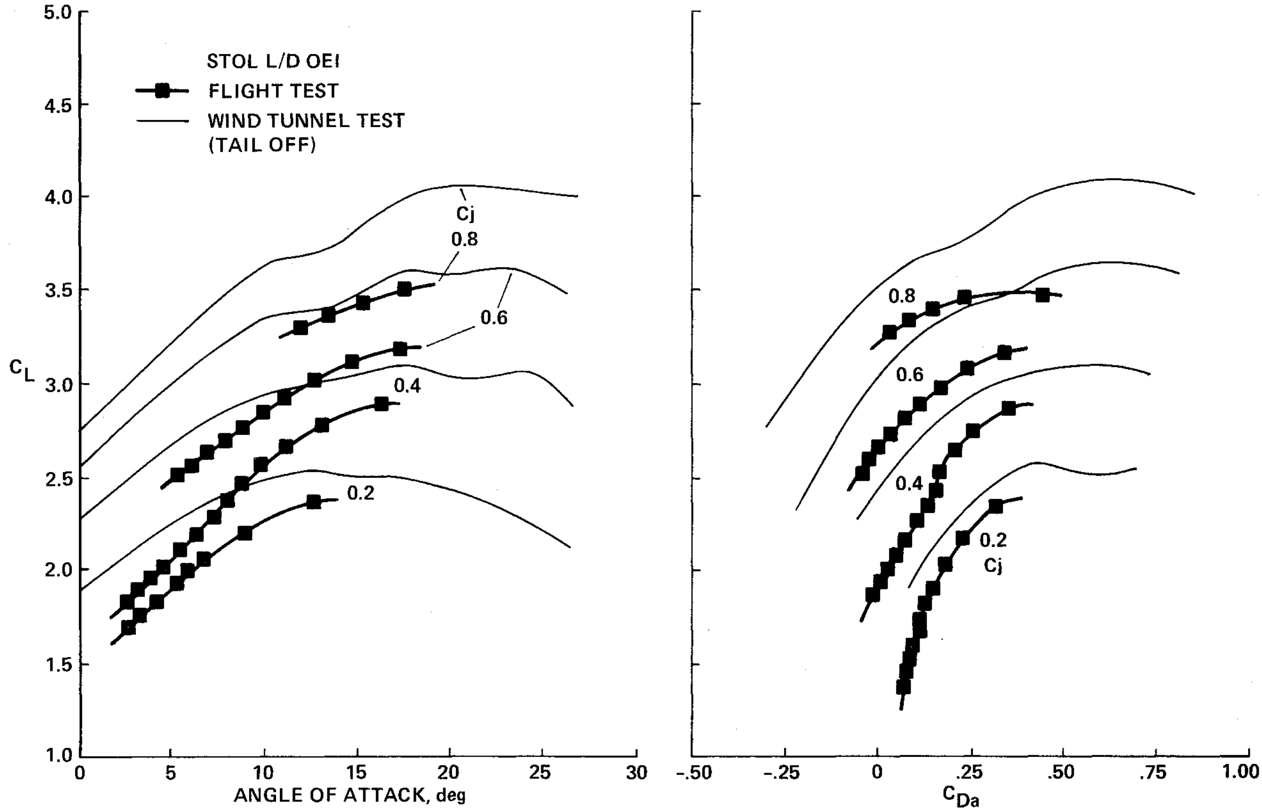


a) C_L vs angle of attack



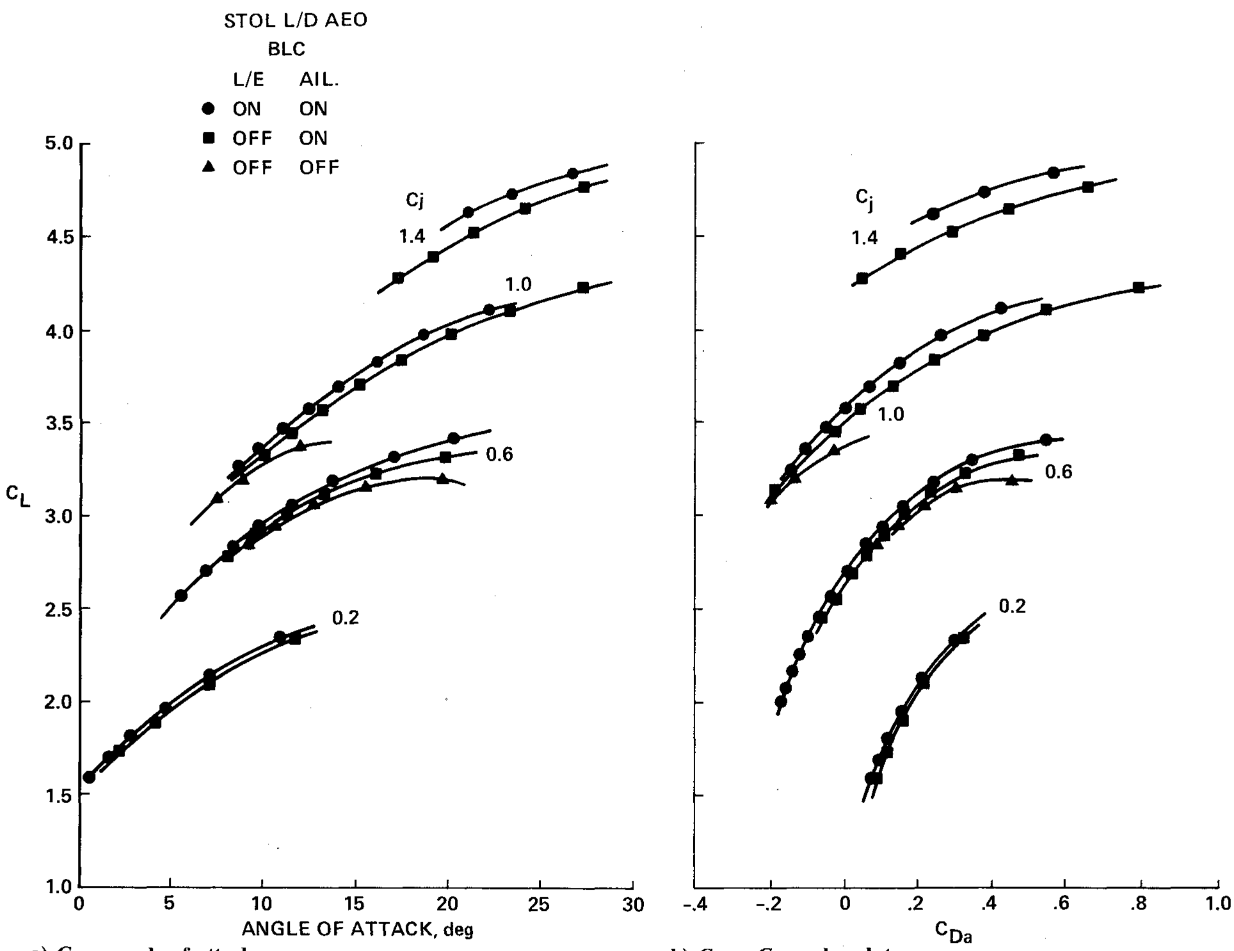
b) C_L vs C_{Da} polar plot

Fig. 9 C_L vs angle of attack and C_L vs C_{Da} polar plot : STOL landing, AEO case.



a) C_L vs angle of attack b) C_L vs C_{Da} polar plot

Fig. 10 C_L vs angle of attack and C_L vs C_{Da} polar plot : STOL landing, OEI case.



a) C_L vs angle of attack b) C_L vs C_{Da} polar plot

Fig. 11 BLC effectiveness.

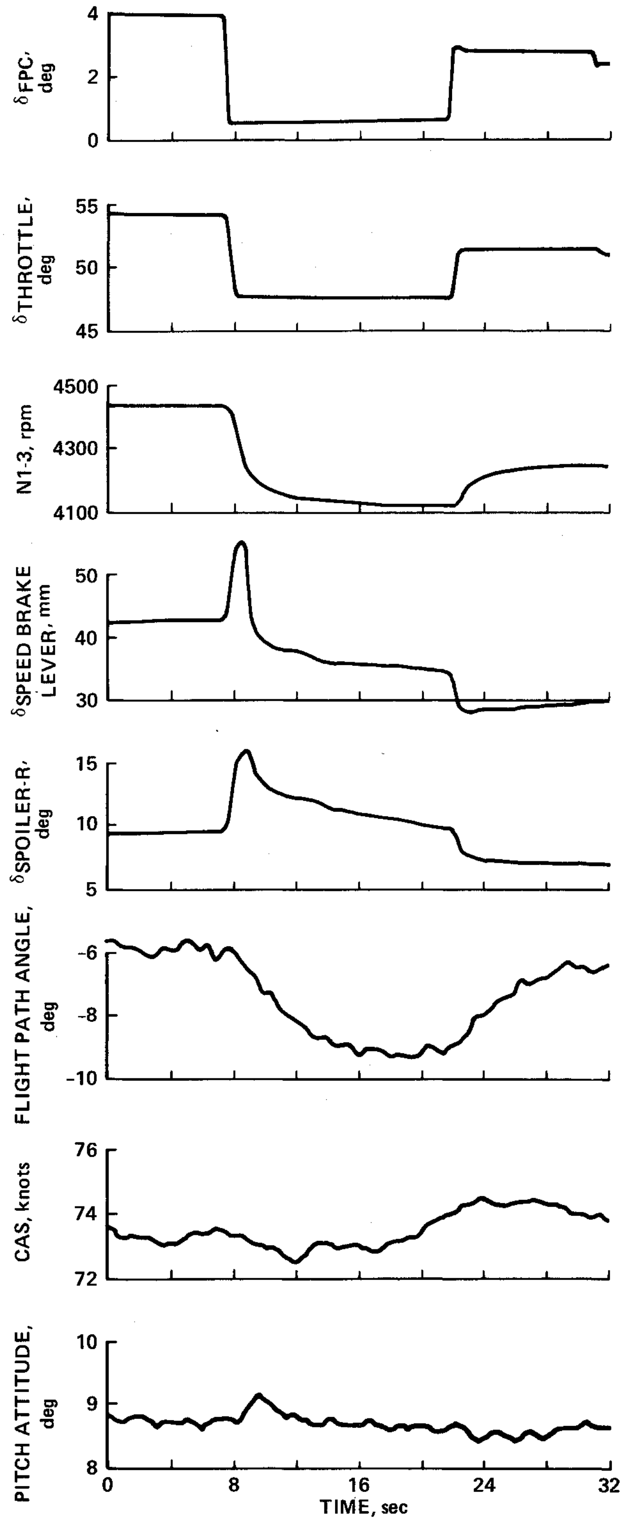


Fig. 12 SCAS FPC mode flight test.

test cases, the OEI does not mean the engine is at full stop, but rather is at ground idle, which has about 10% maximum thrust.

In Figs. 6a and 6b, constant pitch attitude contours are shown. Around the design approach point, that is, 72 kt and -6 deg flight path angle, constant pitch attitude contours are almost perpendicular to the x-axis. This means the speed can be controlled by the pitch attitude and the flight path angle can be controlled by the engine power. The backside piloting technique is suitable for this aircraft at approach.

C_L vs Angle of Attack and C_L vs C_{Da} Diagrams

C_L vs angle of attack and C_L vs C_{Da} polar plot for the STOL landing configuration are shown in Figs. 9 and 10. Figures 9 show the AEO case and Figs. 10 the OEI case, respectively. The aerodynamic drag coefficient C_{Da} is defined as the drag subtracted by the ram drag and normalized by the dynamic pressure and wing area. In Figs. 9 and 10, the parameter C_j is the gross thrust coefficient, that is, the gross thrust normalized by the dynamic pressure and wing area. Flight-test results are compared with the design wind-tunnel test results.

In Figs. 9, the actual lift is less than the design values for the same C_j and angle of attack. This may lead to worse performance than expected, as shown in Fig. 6a. As for the OEI case in Figs. 10, the lift and drag performances are still worse than the design values, however, the aircraft OEI performance itself is better than the wind-tunnel expectation, as shown in Fig. 6b. As design data used in Figs. 9 and 10 were obtained by the tail-off configuration model, the effect of the tail downwash should be taken into account for further discussions.

Boundary-Layer Control Effectiveness

The effectiveness of the BLC is observed in Figs. 11. Fig. 11a shows the C_L vs angle-of-attack diagram and Fig. 11b shows the C_L vs C_{Da} polar plot for the STOL landing configuration and the AEO case. Both ailerons and leading edges have a blowing system that can go on and off independently, and each symbol represents BLC combinations, as shown in the figure. Data for four gross thrust conditions C_j are shown in Figs. 11. The effectiveness of the boundary-layer control is very obvious around the operating point $C_L = 3.5$-4.0. It can be concluded that the aileron BLC is crucial for the operation. However, the leading edge BLC is not considered crucial because there is a slight difference between on and off leading-edge BLC. It could possibly be more feasible not to use the leading-edge BLC and reduce the power loss due to engine bleed.

Flight Path Control Mode Effectiveness

The flight test results of SCAS flight path control mode are shown in Fig. 12. The pilot made a manual stepwise input to the FPC lever equipped on the center pedestal to make a flight path change from -6 to -9 deg. During this test, the pitch attitude is kept constant with the pitch attitude CWS mode on. The engine fan rpm, represented by the no. 3 engine's fan, followed the FPC lever motion with some time constant. The spoiler works through the washout network from 7 deg uprig position to improve the initial motion. The flight path angle changes from -6 to -9 deg in 8 s. The pilot commented the flight path control is rather sluggish for the high-precision touch down point control.[24]

Concluding Remarks

The ASKA was made to provide a flight facility for research on the USB STOL transport. The program included both design and flight research. It was also Japan's first construction of the four-jet-engined aircraft.

In this paper, the flight-tested lift and drag performances, BLC effectiveness, and SCAS FPC mode are discussed. The flight data are a little different from the design data; however, the design performance goals are satisfied within margins. The difference between the flight measured data and the wind-tunnel research may be chiefly because the models used in the wind tunnel are too small to identify the performance. Further discussions on each item should be made, with some additional data such as measurement of the horizontal tail downwash.

Acknowledgments

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