COCKPIT, AVIONICS, PERFORMANCE, FQ, HQ AND WORKLOAD EVALUATION ON L39 ALBATROS FOR LIFT SUITABILITY

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(TEST PILOT)

FW FINAL PROJECT

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The undersigned certify that this report is entirely original work and that where other sources or documents have been used, this is clearly stated.

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Executive Summary

Calgary Ostrogoth Air Force (COAF) was looking to procure L39 Albatros aircrafts to train student pilots in LIFT mission for transition to 5th generation aircrafts. COAF was searching for avionics upgraded L39s of International Test Pilots School (ITPS) for LIFT mission suitability to materialize its purpose.

Test crew went through ground tests for cockpit ergonomics and avionics, inflight tests for mission related performance, flying qualities, handling qualities and workload. Although L39 had proven itself as a trainer and was promoted with some avionics coating, test team created a result effort without ignoring several key parameters that would act as a bridge between L39 and 5th generation platforms.

L39 was found to be incompetent as it didn't introduce symbology of cueing for air-to-air missile and gun attack with lack of ranging capability during offensive BFM. Even though L39's sufficient flying and handling qualities for offensive BFM and close formation flight, its handling qualities during maximum pulling on the brink of lift / thrust boundary and high workload introduced because of its avionics deficiencies in defensive BFM were assessed UNSATISFACTORY (CLASS II). HIGHLY DESIRABLE recommendations over findings were to be:

1. L39 should be equipped with a ranging device either as a sensor or bilateral data link between BFM players and forged with weapon employment cueing system,
2. L39's avionics should be modified to give aural alert for predefined fuel and altitude level,
3. COAF should consider impacts of poor handling qualities of L39 for pulling the stick at the thrust / lift boundary and compare its characteristics for transitioning to 5th generation aircraft.

Four more CLASS III deficiencies were presented into consideration. It would also be recommended to fulfill MIL-F-8785C remaining requirements that couldn't be conducted due to time constraints and lack of onboard test instruments.

L39 evaluated UNSUITABLE for LIFT mission on grounds of a transition aircraft to 5th generation platforms.

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List of Abbreviations

~	Approximately
2D	Two dimensional
3D	Three dimensional
A/C, a/c	Aircraft
ACMI	Air combat maneuvering instrumentation
AFM	Aircraft flight manual
AGL	Above ground level
ALT	Altitude
AoA	Angle of attack
AoB	Angle of bank
ATC	Air traffic control
BD	Battle damage
BFM	Basic fighter maneuvers
C/B	Circuit breaker
CFAS	Canadian Forces Anthropometric Survey
CG	Center of gravity
CHRS	Cooper Harper rating scale
cm	Centimeter
CO	Air to air combat
COAF	Calgary Ostrogoth Air Force
CRM	Crew resource management
CYCE	Centralia airport
CYQS	St. Thomas airport
CYXU	London airport
DACT	Dissimilar aircraft combat maneuvers
DC	Direct current
DEP	Design eye position
DLZ	Dynamic launch zone
EFIS	Electronic flight instrument system
Fa	Aileron force
FADEC	Full authority digital engine control
FCMC	Flight control mechanical characteristics
Fe	Elevator force
FF	Close formation flight
FOD	Foreign object damage
FOV	Field of view
fpm	Feet per minute
FQ	Flying qualities
Fr	Rudder force
FRSR	Free return speed ratio
ft	Feet
FTE	Flight test engineer
FTI	Flight test instrumentation

FTO	Flight test order
FTT	Flight test technique
HMI	Human machine interface
HOTAS	Hands on throttle and stick
HSI	Horizontal situation indicator
HUD	Head up display
IMC	Instrument meteorological conditions
IP	Instructor pilot
IR	Infra-red
ITPS	International Test Pilot School
ITTC	ITPS tactical training center
KIAS	Knot indicated airspeed
KIO	Knock it off
km/h	Kilometer per hour
kts	Knots
L	Local time
lb	Pound
lbf	Pound force
LDDS	Lateral directional dynamic stability
LDS	Longitudinal dynamic stability
LDSS	Lateral directional static stability
LH	Left hand
LIFT	Lead in fighter training
LMS	Longitudinal maneuver stability
LSS	Longitudinal static stability
MAC	Mean aerodynamic chord
MCP	Maximum continuous power
MFD	Multi-function display
MHz	Megahertz
min	Minute
msec	Millisecond
MSL	Mean see level
N/A	Not applicable
NAV	Navigation
NM	Nautical mile
NRST	Nearest
N_Z	Load factor
OAT	Outside air temperature
PFD	Primary function display
PFR	Post flight report
PIO	Pilot induced oscillation
Proc.	Procedure
RH	Right hand
RPM	Round per minute
RS	Rating scale
RTB	Return to base

RWY	Runway
SD card	Security digital card
sec	Second
SHSS	Steady heading sideslip
SPD	Speed (airspeed)
SPO	Short period oscillation
TAI	Turkish Aerospace Industry
TC	Turn circle
TP	Test point
TP	Test pilot
TurAF	Turkish Air Force
VFR	Visual flight rules
V_H	Maximum airspeed in level flight with maximum continuous power
V_{MAT}	Airspeed for maximum available thrust
VMC	Visual meteorological conditions
V_{MO}/M_{MO}	Maximum operating limit speed
V_{NE}	Never exceed speed
V_{NO}	Maximum structural cruising speed
V_S	Stall speed
V_T	Trim speed
w/o	Without
WL	Workload
WLSS	Wings level sideslip
WUT	Wind up turn
β	Sideslip
Δ	Delta (difference)
δa	Aileron deflection
δe	Elevator deflection
δr	Rudder deflection

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SECTION 1 Introduction

1.1 Background

The Calgary Ostrogoth Air Force (COAF) was looking to purchase several Aerovodochody L39 Albatros aircrafts from an eastern European country. The intended use of the aircraft was Lead in Fighter Training (LIFT). To minimize the gap for transitioning to 5th generation fighters, COAF had contracted ITPS to first undergo a front cockpit upgrade of the L39. ITPS had modified its own aircrafts with reconfigurable electronic displays for this evaluation, supported by the "Stallions ACMI" and debriefing software. Test team, consisting of one test pilot from TurAF (Turkish Air Force) and one flight test engineer from TAI (Turkish Aerospace Industry), was given the task to carry out the evaluation of the modified L39 and supporting ACMI for the LIFT mission.

1.2 Purpose of the Test

The main objectives of the assessment were to:

- Evaluate L39 performance for key parameters (clean / cruise configuration) relevant to the mission and compare it to the legacy aircraft as published in AFM (Annex A.1).
- Evaluate aircraft flying qualities (clean / cruise configuration) according to MIL-F-8785C [5].
- Evaluate HQ characteristics for LIFT mission.
- Evaluate ergonomics / cockpit workload for the relevant mission elements.
- Provide an overall recommendation on the suitability of upgraded L39 and supporting "Stallions ACMI" debriefing software for LIFT mission of COAF.

As a secondary objective, test team would recommend a setting (pages to display) that would become the standard operational configuration for LIFT mission and evaluate workload required with the proposal.

1.3 Assessment Philosophy

Assessments were aimed to evaluate objectives (paragraph 1.2) according to relevant flight test order [1].

Ground assessment was planned to comprise of cockpit ergonomics, cockpit reachability zone analysis, outside and inside FOV evaluation, EFIS evaluation, HMI assessment of cockpit controls and workload of EFIS. ACMI software was assessed to observe capabilities of the debriefing system.

Performance test points were aimed to compare results with AFM (Annex A.1) if they were inside the acceptance margin of 10% that was mandated by COAF. Main subjects were given as stall, climb and maneuver performances by FTO. Stall speed determination and stall characteristics test points were designated as precedence of the test campaign. This would help test pilot to determine 1.1Vs airspeed to start level acceleration for climb performance, beware

of 1.1Vs minimum airspeed limit throughout test campaign except stall tests and get used to stall behaviors of the aircraft in case of any unintentional stall contingencies.

Climb performance was conducted to find best rate of climb parameters which were considered prominent to ascent from floor to initial BFM setup altitude with an efficient fuel consumption after termination of the setups to enhance BFM setups' reiteration numbers. Manoeuvre performance tests were conducted to plot doghouse chart of L39 to find lift boundary, thrust boundary, sustained / instantaneous maximum turn rate / minimum turn radius airspeeds.

Climb and maneuver performance target altitude was determined as 4000 m (13 100 ft) MSL because of the considerations discussed in next paragraph.

As pilots would conduct overwhelmingly rate or radius fight during BFM missions, 200 KIAS corresponding to sustained maximum turn rate airspeed and 140 KIAS corresponding to sustained minimum turn radius airspeed of 4400 kg aircraft weight (9800 lb aircraft weight representative for 400 lb total mass of flight crew) was picked from maneuver performance chart (Figure 1) derived from AFM (Annex A.1). Dedicated maneuver performance chart was for 4000 m (13 100 ft) elevation and "0" drag index. Other maneuver performance charts for two altitude options close to 4000 m were 2000 m (6600 ft) and 6000 m (19 700 ft). 6600 ft was not found suitable considering floor determination (paragraph 1.7) and 19 700 ft was over the upper limit given by FTO [1] (paragraph 1.6). Therefore, 200 KIAS and 140 KIAS airspeeds would be focused as two target airspeeds by means of evaluating flying qualities and handling qualities of air-to-air combat phase and 13 100 ft MSL would be the interest altitude to assess climb and maneuver performance tests.

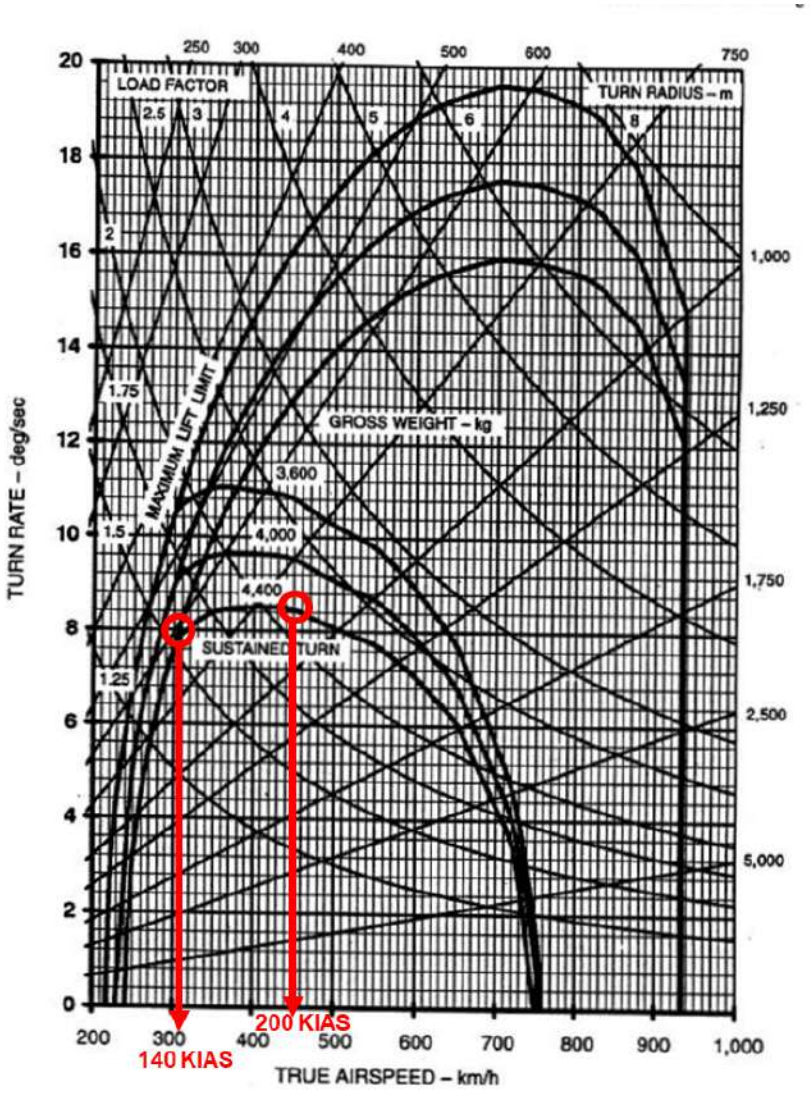


Figure 1: **L39 Sustained Minimum Turn Radius and Maximum Turn Rate Airspeeds**

Overall representative mission profile was depicted in Figure 2.

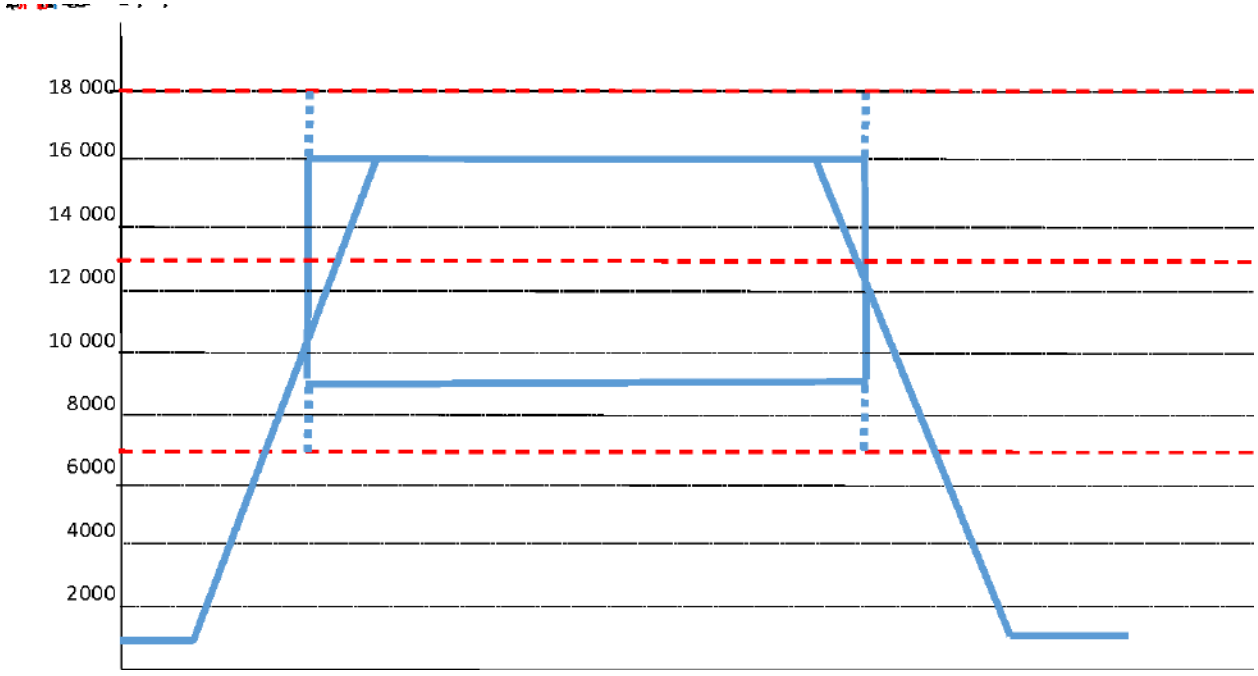


Figure 2: Representative BFM Mission Profile (Ground Elevation 1000 ft)

Flying qualities test points were aimed to evaluate the aircraft's flying qualities characteristics according to MIL-F-8785C [5].

Typical maneuvers for HQ and workload evaluations were thought to be:

- Basic fighter manoeuvres (BFM),
- Formation flight (close formation).

Offensive BFM was flown simulating rate fight at 200 KIAS to assess HQ and workload by additional tasks determined. Defensive BFM was flown simulating radius fight at 140 KIAS to evaluate HQ and workload with additional tasks.

Formation flight was evaluated by means of HQ and workload at airspeed of 190 KIAS. The rationale of this airspeed choice was to be below the limit airspeed of 200 KIAS of tower control zone (generally applicable internationally) during the approach to initial point of circuit. Pilots typically would prefer to climb, descent and fly close formation at 190 KIAS which assures tower control zone airspeed limit and satisfies comfort level as legacy aircraft operational pilots used to, although best rate of climb airspeed was given as 205 KIAS in L39 flight checklist (Annex C.2).

1.4 Aircraft Description

L39C was a single turbofan engine, two-seater with ejection, subsonic aircraft manufactured by Aero Vodochody. The low-set, straight wing had a double-taper planform with 2.5° dihedral from the roots, fuel tanks permanently attached to the wingtips. The trailing edge had double-slotted

trailing edge flaps inboard of mass-balanced ailerons; the flaps were separated from the ailerons by wing fences. An electrical trimming system was present, the flaps and the trim system were connected to counteract the pitch change during configuration change. The swept vertical tail had an inset rudder. Variable-incidence horizontal stabilizers with inset elevators were mounted at the base of the rudder and over the exhaust nozzle. Side-by-side airbrakes were located under the fuselage ahead of the wing's leading edge. The flaps, landing gear, wheel brakes and air brakes were powered by a hydraulic system. The fully reversable flight controls were pushrod-actuated and feature electrically powered servo tabs on the ailerons and rudder. The engine control was done manually by the pilot without automatic support by a FADEC-type system, which caused the engine sensitive to certain operational conditions such as high angles of attack. The aircraft was fitted with a hydraulically actuated retractable nosewheel undercarriage. The main landing gear legs retracted inward into wing bays while the nose gear retracted forward. Steering was provided by differential braking of the two main landing gear wheels. The aircraft was not fitted with an autopilot.

Further information about case aircraft could be found in Annex A and flight controls were introduced in detail via Annex B.

The aircraft external dimensions were shown in Figure 3.

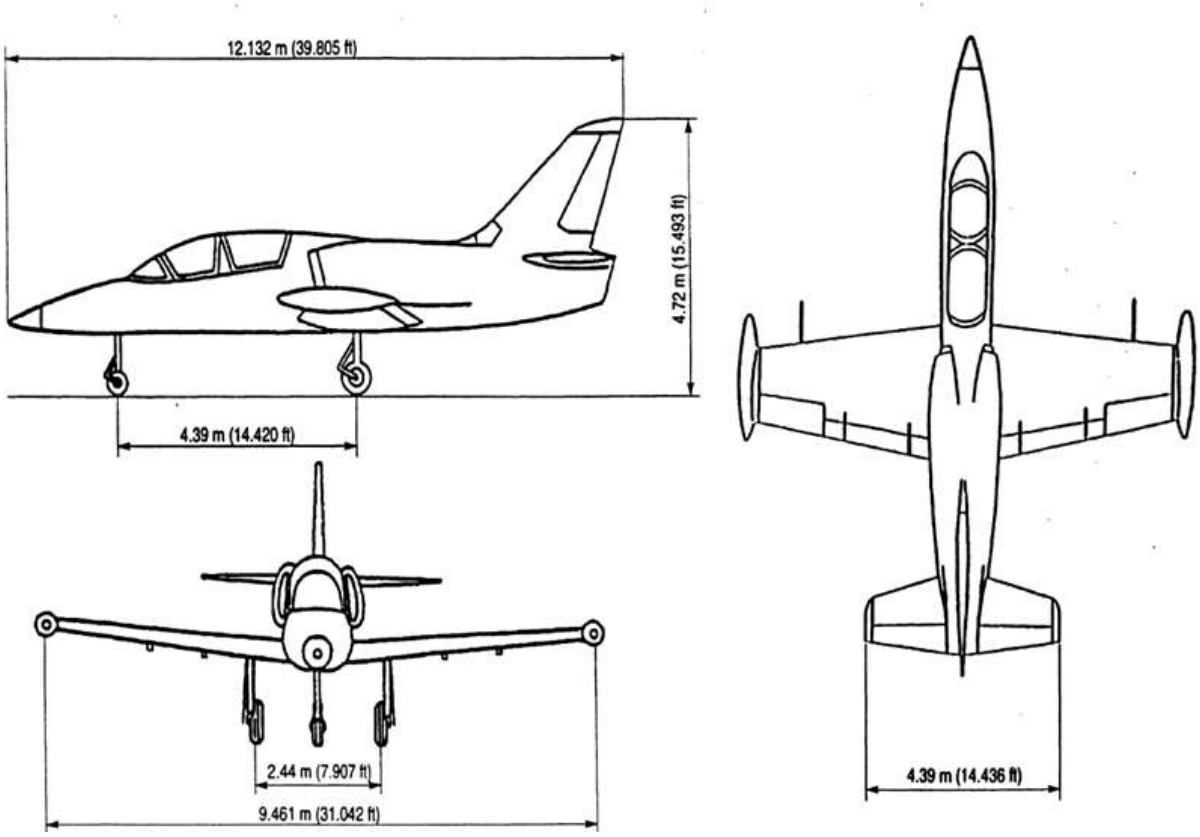


Figure 3: L39 Structural Dimensions

Front cockpit of L39C had been upgraded with two touch screen instruments. Garmin G3X Touch Avionics Suite features two 10.6 inches GDU 460 displays in the front cockpit (Figure 4). The system was capable of recording flight data with 1Hz.

Figure 4: Garmin G3X GDU 460 Front Cockpit Displays

1.5 Scope of the Test

Test team of two, one test pilot and one flight test engineer, planned and performed test campaign whose experience and anthropometric data were given in Annex C.6 and Annex C.7 respectively.

Ground tests were conducted in ITPS hangar with a spare L39 aircraft (Annex C.1, C.3) in 2 hours period. External power was implemented when necessary.

COAF did not consider night flying and IMC conditions as part of this mission, therefore, all test campaign was conducted in day VMC conditions. COAF student pilots would fly in front seat, therefore, evaluations were performed for only front seat operations.

Due to mission requirements, all test campaign was planned only with clean / cruise configuration inside normal operating envelope. Weight and balance sheets were attached in Annex D.1.

Test flight campaign was completed in 4 sorties as given in Table 1. All flight tests were conducted from London international airport (CYXU).

Flight #	Aircraft #	Date	Duration	Crew	Subject
1	1 X L39	22 NOV 2022	01:22	Sukru Yilmaz	FQ
2	1 X L39	23 NOV 2022	01:08	Serkan Demir	Performance + (FQ)
3*	1 X L39	02 DEC 2022	00:51	Sukru Yilmaz	BFM / Formation
4*	1 X L29	02 DEC 2022	00:51	Serkan Demir	BFM / Formation
* Sorties flown together as formation					

Table 1: Summary of Sorties Flown

Performance tests were conducted at target altitude of 13 100 ft MSL. Climb performance was determined by level acceleration method instead of time-consuming sawtooth climb method which was suitable to aircraft's fast jet capability and manoeuvre performance was determined by stabilized turns (front / back side) and wind up turns.

FQ tests' target altitude was chosen below 10 000 ft MSL due to ATC coordination concerns for prolonged time (Figure 5). Test team decided to evaluate FCMC, LSS, LDS, LDSS, LDDS, LMS and roll performance by means of FQ evaluation at 200 KIAS and 140 KIAS.

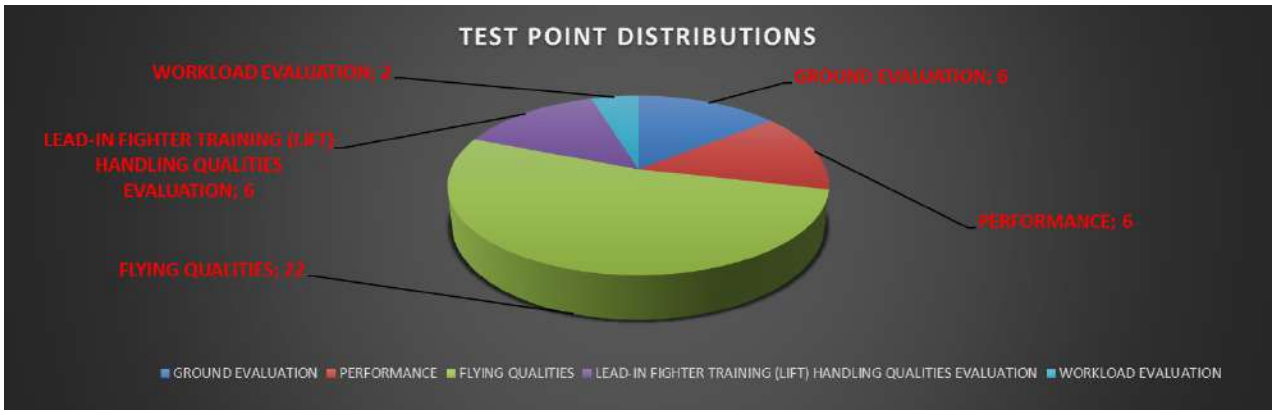


Figure 5: Test Subject Ratios

1.1Vs to V_H airspeed range was used as limit in scope of evaluation except stall tests.

Test aircraft, L39 Albatros was defined as Class IV and Category A (by means of flight phase) in MIL-F-8785C [5] for LIFT mission. In this document, operational airspeed envelope for air-to-air combat (CO) and close formation flight (FF) was defined from $1.4V_S$ to V_{MAT} where 140 KIAS and 200 KIAS target airspeeds (for FQ / HQ) were inside the operational envelope.

HQ and workload tests were conducted throughout the representative BFM and formation flight tasks.

1.6 Limitations

Test limitations forged either by FTO or test team due to risk mitigation or test effectiveness were listed below:

- As risk mitigation, max load was limited to +6 G.
- Below 10 000 ft MSL maximum airspeed would be 250 KIAS.
- Operations was limited up to 18 000 ft MSL.
- L39 uncontrolled flight ejection altitude was determined as 6000 ft AGL for risk mitigation.
- BFM representative tasks would be terminated at floor or 1.1 Vs whichever comes first.
- 400 litres of fuel were determined as BINGO for RTB.
- 250 KIAS of airspeed would not be exceeded to minimize fuel consumption to cover all planned test points in a limited test campaign except level acceleration method and front side stabilized turn (up to V_H).
- Soft deck altitude (8000 ft AGL) of ITTC BFM SOP [23] was considered as floor (2000 ft additional buffer to uncontrolled ejection altitude) during BFM setups.
- Operator limited flight hours to 01:40 from step to returning in parking area for the first two sorties. 3rd and 4th sorties were flown as formation and second aircraft was allocated as L29 Delfin due to maintenance constraints applied to L39 aircrafts. Log data couldn't be merged due to L29's incapability, thus, ACMI software evaluation could be done with pre-saved mission.
- Some test points couldn't be repeated for reciprocating side due to limited time.
- Some flying quality tests couldn't be planned due to time constraint of test campaign and lack of onboard FTI comprise of forces and deflections of controls and AoA data as mentioned in the dedicated paragraphs of section 2.
- Formation and BFM test points could be conducted between 5000 ft to 7500 ft due to 8000 ft overcast clouds.

1.7 Description of the Role

BFM mission would start with take-off phase as single ship and continue with rejoin during climb out while navigating to working area. Rejoin could be either tactical or close formation under pilot discretion.

Pilots would be expected to conduct offensive and defensive BFM maneuvers inside the working area. As BFM mission was susceptible to stalls, departures, or spin entries as excessive multi axis control inputs were being made, L39's uncontrolled ejection altitude should be considered at least 6000 ft AGL, thus, letting pilot to safe separation from aircraft in case of ejection sequence contingencies. It would be better for pilots to select an upper-level floor to execute BFM training in a safe manner which could be considered 2000 ft above safe altitude

would make the floor 8000 ft AGL. Pilots would prefer to determine upper limit of working area in discretion.

Offensive and defensive BFM setups would be continued until termination close to floor. Two aircrafts would climb back to initial setup altitude maintaining best climb rate speed to save fuel. As BFM mission comprised of high throttle settings, efficient fuel management would be prominent to save fuel and increase the number of setups.

In BFM training, adversary aircraft would simulate different capabilities as thrust limited, turn limited or similar bandit options. Those cases would lead pilots to choose either rate fight (with maximum sustained turn rate airspeed) or radius fight (with minimum sustained turn radius airspeed). Those two types of wars would stand for both offensive and defensive positions.

During RTB section, aircrafts would rejoin to close formation to conduct battle damage check as BFM mission would require high G and high thrust which could be able to damage aircraft's structure. Typically, two aircrafts would approach to airbase with close formation reporting initial point of runway. After executing break, aircrafts would separate to land single ship with intervals.

1.8 Tests Made

In scope of the flight test plan (Annex E.1), implemented tests and test techniques according to test matrix (Annex E.2) were listed below:

1.8.1 Ground Evaluation

- Cockpit assessment
- HMI assessment of avionics displays
- HMI assessment of cockpit controls
- EFIS evaluation
- ACMI debriefing software evaluation

1.8.2 Performance

- Stall performance
  - Wings level idle unaccelerated stall
- Climb performance
  - Level acceleration
- Manoeuvre performance
  - Steady turn, front side
  - Steady turn, back side
  - Wind-up turn

1.8.3 Flying Qualities

- Flight control mechanical characteristics (FCMC)
- Longitudinal static stability (LSS)

    - Stabilized point method
- Longitudinal dynamic stability (LDS)
    - Short period mode – doublet
    - Phugoid mode
- Longitudinal manoeuvre stability (LMS)
    - Stabilized turn
- Lateral directional static stability (LDSS)
    - Wings level sideslip (WLSS)
    - Steady heading sideslip (SHSS)
- Lateral directional dynamic stability (LDDS)
    - Dutch roll mode
    - Rolling performance, bank-to-bank roll
- Stall characteristics
    - Wings level idle unaccelerated stall
    - 30° bank idle unaccelerated stall
    - 30° bank 75% MCP accelerated stall

1.8.4 Handling Qualities and Workload

- Formation flight (close formation)
    - Steady fingertip
    - Manoeuvring fingertip
    - Capture fingertip
    - Capture line astern
- Basic fighter manoeuvres (BFM)
    - Offensive BFM (Annex E.5)
    - Defensive BFM (Annex E.6)

Further details could be found in test cards (Annex E.3) and post flight reports (Annex E.4).

1.9 Instrumentation

Ground assessment was conducted by taking photos and using Dioptra application to get elevation / azimuth angles with smartphone and tape measure was used for distance.

Ground assessment and data flights were overwhelmingly dependent on handwritten data. iLevel and GoPro camera with voice record function were exploited during FQ and performance test sorties. Stopwatch was operated for time hacks; OAT was introduced by L39 onboard systems. GoPro was used to assure handwritten data if in doubt. Specifically, iLevel data was exploited for roll and yaw rate to plot Dutch roll graphs, roll rate to calculate roll mode time constant and to plot roll mode graph. Since the aircraft didn't have onboard FTI to measure control forces, they were collected qualitatively. During LSS test points, force gauge wasn't preferred in order not to lose time in a limited test campaign. Sideslip information from iLevel was available but during static lateral / directional tests, sideslips were collected from heading

changes by hand, so trusted heading difference sideslips were implemented as iLevel had some deviations.

Aircraft onboard log data were also collected. Further details about instrumentation could be found in Annex F.1.

SECTION 2 Results and Discussions

Ground evaluation was performed in ITPS hangar between 10:30-12:30 local time on 25th November 2022. Aircraft was under artificial light condition and OAT was measured to be 22°C. External power was introduced to L39 to be able to assess indication lights and avionics displays in the cockpit.

First sortie (Table 2) was performed at north of London airport between 5000 ft to 11 000 ft MSL altitude block. Test flight was performed through 11:30-12:52 local time under VMC, clear of clouds, calm wind conditions, and OAT was varying +1°C to -1°C about 8000 ft. Aircraft CG was mid 23.1% to 22.3% MAC.

TP#	DESCRIPTION	SPD (KIAS)	ALT MSL (ft)	CONFIG.
2.1 / 2.2 / 3.20	Stall controllability / performance / characteristics wings level, idle, unaccelerated	140	8000	Cruise
3.1	FCMC	140	8000	Cruise
3.2	LSS	140	8000	Cruise
3.14 / 3.12	SHSS / WLSS	140	8000	Cruise
3.16	Dutch roll	140	8000	Cruise
3.18	Roll performance	140	8000	Cruise
3.3	FCMC / LSS	200	8000	Cruise
3.15 / 3.13	SHSS / WLSS	200	8000	Cruise
3.17	Dutch roll	200	8000	Cruise
3.19	Roll performance	200	8000	Cruise
3.4	Frequency sweep	140	8000	Cruise
3.5	SPO doublet	140	8000	Cruise
3.8	Phugoid	140	8000	Cruise
3.6	Frequency sweep	200	8000	Cruise
3.7	SPO doublet	200	8000	Cruise
3.9	Phugoid	200	8000	Cruise

Table 2: First Sortie Executed Test Points

Second sortie (Table 3) was performed at north of London airport between 5500 ft to 15 000 ft MSL altitude block. Test flight was performed through 14:13-15:21 local time under VMC, clear of clouds, calm wind conditions, and OAT was varying +1°C to -11°C throughout the altitude block. Aircraft CG was mid 23.8% to 22.9% MAC.

TP#	DESCRIPTION	SPD (KIAS)	ALT MSL (ft)	CONFIG.
2.3	Level acceleration	110 - 310	13 000	Cruise
2.4	Steady turn, front side	306	13 000	Cruise
2.5	Steady turn, back side	200	13 000	Cruise
2.6	Wind up turn	250	13 000	Cruise
3.10	Stabilized turn	200	8000	Cruise
3.11	Stabilized turn	140	8000	Cruise
3.21	Stall characteristics 30° bank, idle, unaccelerated	150	8000	Cruise
3.22	Stall characteristics 30° bank, 75% MCP, accelerated	150	8000	Cruise

Table 3: Second Sortie Executed Test Points

Third and fourth sorties (Table 4) were performed with formation at north of London airport between 5000 to 7500 ft MSL altitude block. Weather had light turbulence with altitude wind of 200° / 22 knots, below overcast clouds of 8000 ft MSL. Test flight was performed through 15:12-16:03 local time. Aircraft CG was mid 23.6% to 22.8% MAC.

TP#	DESCRIPTION	SPD (KIAS)	ALT MSL (ft)	CONFIG.
4.1 / 5.1	Steady Fingertip	190	7500	Cruise
4.2 / 5.1	Maneuvering Fingertip	190	7500	Cruise
4.3	Capture Fingertip	190	7500	Cruise
4.4	Capture Line Astern	190	7500	Cruise
4.5 / 5.2	Offensive BFM	200	7500	Cruise
4.6 / 5.2	Defensive BFM	140	7500	Cruise

Table 4: Third / Fourth Sorties Executed Test Points

2.1 Ground Evaluation

2.1.1 Cockpit Ergonomics

Cockpit ergonomics and human machine interface assessment was performed under the conditions of ground evaluation referring to ITPS Cockpit Assessment Lecture Notes [6] and ITPS Anthropometrics and Ergonomics Lecture Notes [7].

Evaluation of cockpit ergonomics were started with entrance to cockpit. Test pilot whose anthropometric data was given in Annex C.7 was worn of flight suit, boots, G suit, helmet, and kneepad (when needed). Aircraft had integrated ladders for pilot's rise and at the time feet on

them, it was slightly difficult to open canopy because of its heavy weight. After opening the canopy, entrance to cockpit was made with feet on seat and then be seated. Stick was found rested towards very aft position and pilot had to move it forward to be able to be seated. This motion caused elevator's down and coupled aileron movement. Supporting pictures were given in Figure 6.

Figure 6: Canopy Movement and Stick Backward Lean

After being seated, pilot fastened and tightened his belts which was easy to operate. After tightening seat belts, pilot had slight difficulty to reach rudder pedal adjustment and to close canopy due to its heavy weight. Stick rested against test pilot's belly every time with its natural tendency, which was assessed uncomfortable by test pilot. There was no lock / unlock function of restraint harness, so, zone 3 assessment (harness unlocked) couldn't be done by means of reachability. Following settlement in the cockpit, test pilot tried to reach primary and secondary controls which were all commented favorable except one item to be discussed in due paragraphs.

After strapping, test pilot also considered about releasing his ties from seat during an evacuation. Harness attachments were easy to disconnect, but oxygen hose didn't have a quick disconnect that consumed some time to get rid of. Heavy canopy would also have a minor but annoying effect in case of emergency exit.

While external power was introduced to aircraft, pilot put battery and avionics switches to ON. Seat adjustment could be done in this way, and it was easy to operate. Seat left side wall had a reference to establish design eye point but depending on ground personnel's support (Figure 7).

Cockpit room was found to have enough space to assure test pilot's movements. After applying electrical power, test pilot observed inadvertent movement of trim due to resting on test pilot's belly as trim switch was impacted by pressure of test pilot's body.

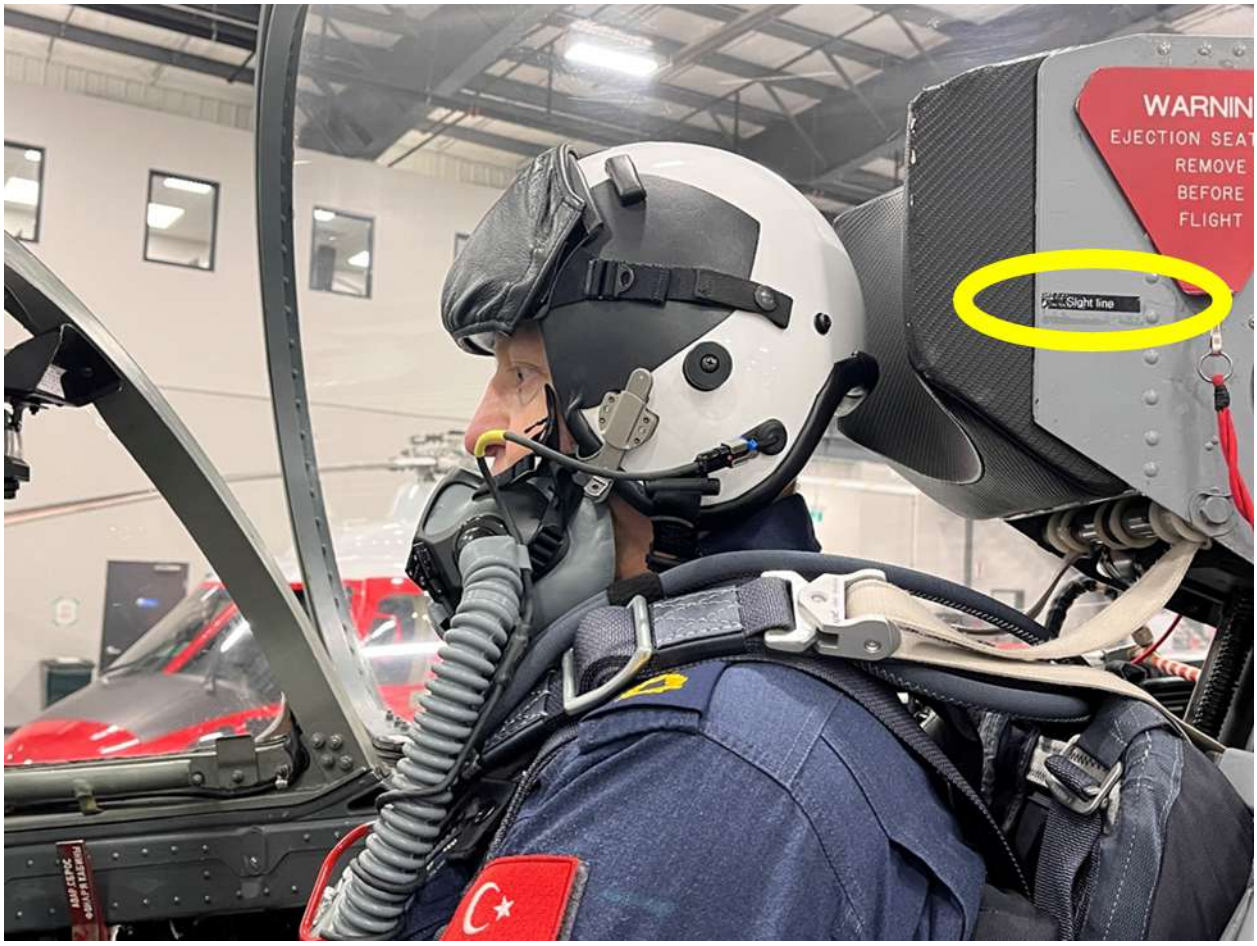


Figure 7: DEP Feature

As seat didn't have a lock / unlock function for harness, pilot tried to reach functional and maximum zones with tight strapped condition. Every switch, knob, lever was inside zone 1 except rudder pedal adjustment handle and warning / caution lights test button which were assessed to be in zone 2 as shown in Figure 8.

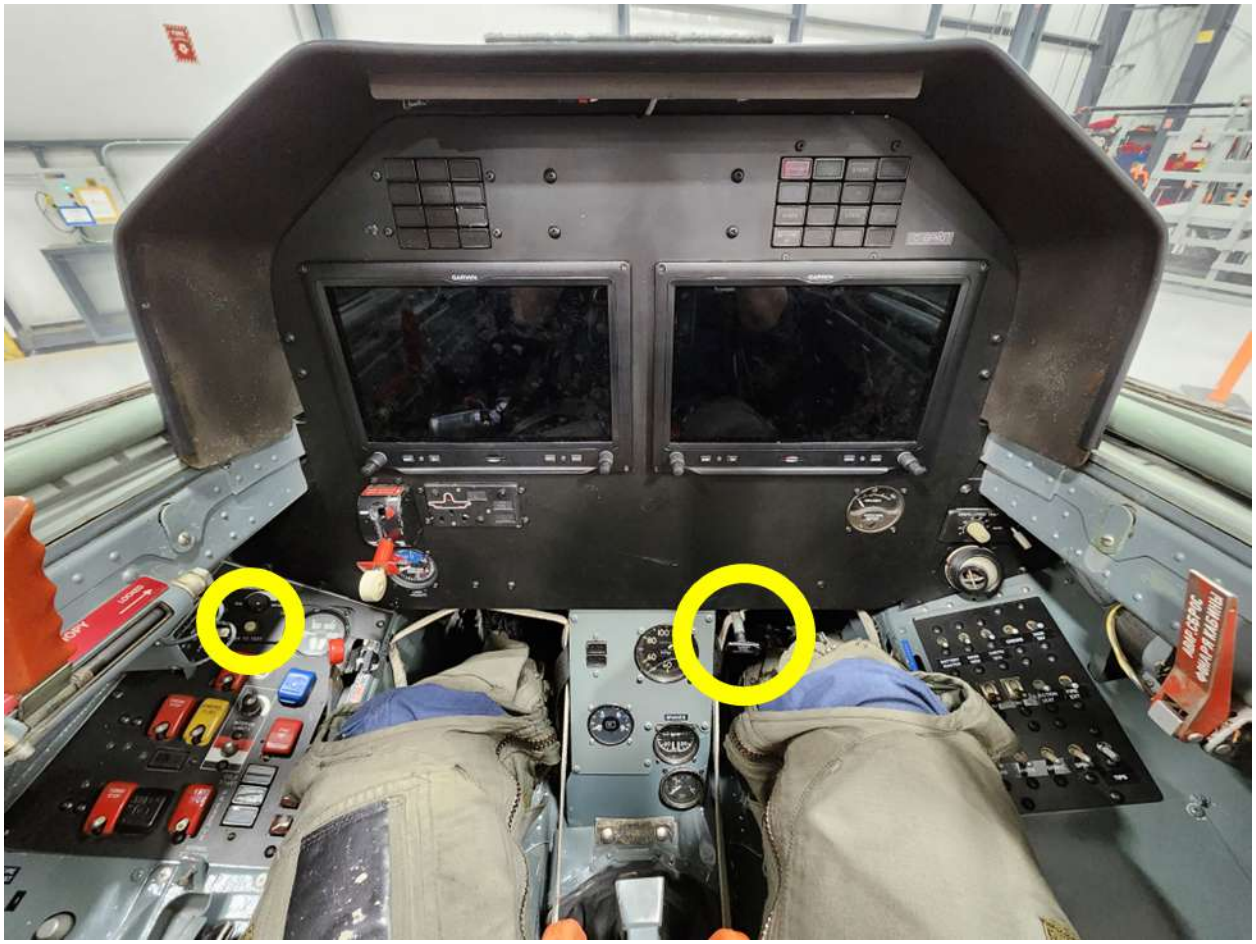


Figure 8: Zone 2 Reachable Items

Overall test items were summarized in Table 5 as shown below.

Test Item	Notes
Access to cockpit (Front)	Heavy canopy Stick backward tendency
Establish and record DEP	DEP reference Sufficient
Ease of seat adjustment	Sufficient
Ease of movement	Sufficient
Seat adjustment for extreme position	Sufficient
Seat restraint - to reach - adjust - lock – unlock	No lock / unlock Sufficient
Pedal adjustment for extreme position	Sufficient
Space and room for equipment	Sufficient
Primary controls – Stick	Stick backward tendency
Primary controls – Pedals, throttle	Sufficient
Secondary controls - Landing gear, flaps, trims	Sufficient
Each controls' switch operation	Sufficient
Use of Normal / Emergency Checklist	Sufficient
Interference with other equipment while pilot cockpit movements	No oxygen quick disconnect function Stick backward tendency
Zone 1: Restraint harness locked-functional reach (All controls that need to be used in takeoff, landing, and escape phases of flight)	Sufficient
Zone 2: Restraint harness locked-maximum functional reach (Primary flight and proportion controls and emergency controls other than escape controls)	Rudder pedal adjustment Warning / caution panel test
Zone 3: Restraint harness unlocked	N/A

Table 5: Cockpit Ergonomics and HMI Summary

COAF student pilots would prefer to be in a user-friendly cockpit environment to be able to reserve their energy for high energy requiring tasks of BFM mission. Poor cockpit design would always trigger workload that could lead excessive energy and motivation consumption. Considering transition to 5th generation aircraft, compatible cockpit ergonomics and HMI would allow student pilots to evolve in a smooth way. Even though, upgraded L39 had prominent features by means of new glass cockpit displays, stick backward pressure to pilot's belly and lack of oxygen hose quick disconnect ability could impact student pilots' adapting.

Stick backward tendency would cause inadvertent trim motions that should be closely monitored by aircrew either with standard operation procedures or CRM support. Otherwise, a fully or partially moved trim tab other than neutral position could impact take off safety by abnormal motion of main controls that might lead even a land crash before starting allocated BFM mission. This might not be scope of specific BFM mission but should be taken into consideration as BFM missions couldn't be started without a safe take off. On ground, keeping stick away from body could lead higher workload which would be minor but annoying. Besides that, while

entering cockpit, pilot's obligation to move stick forward to be seated and strapped could cause ground personnel injuries particularly close to ailerons rather than elevator as the aircraft's tail height was quite enough for clearance.

The other consideration could be given to oxygen quick disconnect disability. COAF student pilots, who were dedicated to adapting themselves to a challenging mission and try to step forward to 5th generation aircraft could miss some minor seen details like ground egress. Student pilots who skipped that important sneaky threat could be susceptible to anomalies. Ground evacuations without quick disconnect oxygen hose could lead injuries during jump out from L39 or late evacuations in case of time matter during a fast pace exposed to student pilots.

Warning / caution test button which was expected to be in zone 1 could be important during particular emergency applications. As some emergency situations would require the correct operation of warning / caution lights, student pilots flying BFM missions could be faced to this contingency as they could hardly reach to test button to implement emergency checklist items after abandoning task could lead them to increasing workload in a stressful time pacing situation.

L39 was assessed UNSATISFACTORY (CLASS III) considering minor but annoying lack of quick disconnect function of oxygen hose, stick backward tendency and warning / caution test button position of zone 2.

Student pilots should be exposed to simulated contingencies about ground evacuation and before take-off controls (control of trim tabs) to be implemented into their pilot operation checklists, SOPs, and flight briefings (DESIRABLE-SAFETY).

A CRM contract and SOP should be forged with maintenance personnel in order not to be close to ailerons during hot cockpit ground operations (DESIRABLE-SAFETY).

Warning / caution test button position should be moved to zone 1 as it should be interpreted as emergency controls (DESIRABLE-SAFETY).

2.1.2 FOV (Inside / Outside)

Cockpit inside and outside FOV assessment was performed under the conditions of ground evaluation referring to ITPS Cockpit Assessment Lecture Notes [6], AC 23.1311-1C Installation of Electronic Display in Part 23 Airplanes [3] and MIL-STD-850B Aircrew Station Vision Requirements for Military Aircraft [21]. Test pilot, whose anthropometric data was given in Annex C.7, was worn of flight suit, boots, G suit, helmet, and kneepad.

After test pilot's settlement in the cockpit and positioning of design eye point, tape measure and smartphone (Dioptra application) were used to determine distances and angles according to pilot's eye.

In accordance with Figure 9 derived from AC 23.1311-1C [3], upgraded avionics displays (PFD and MFD) and warning / caution lights were found inside optimum FOV of test pilot. Positions of the dedicated instruments was shown in Figure 10.

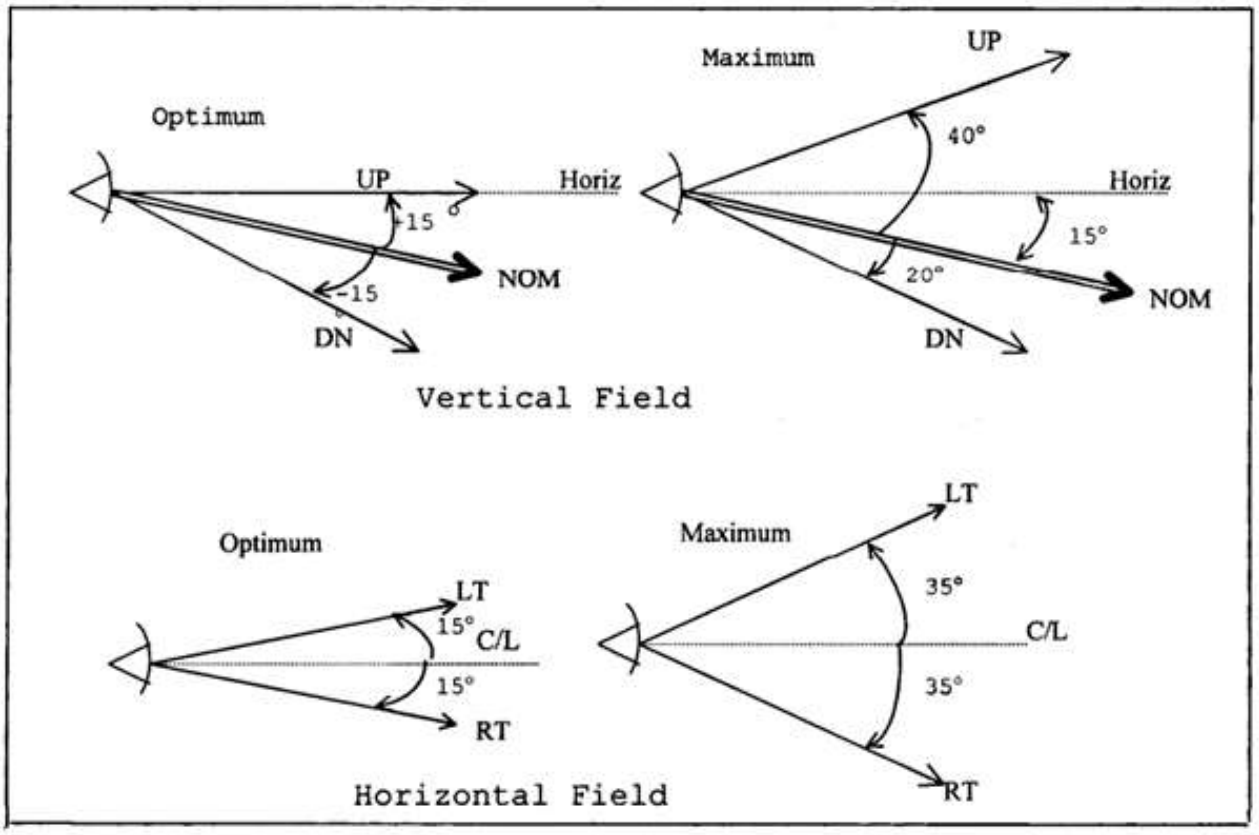


Figure 9: Optimum and Maximum FOV References

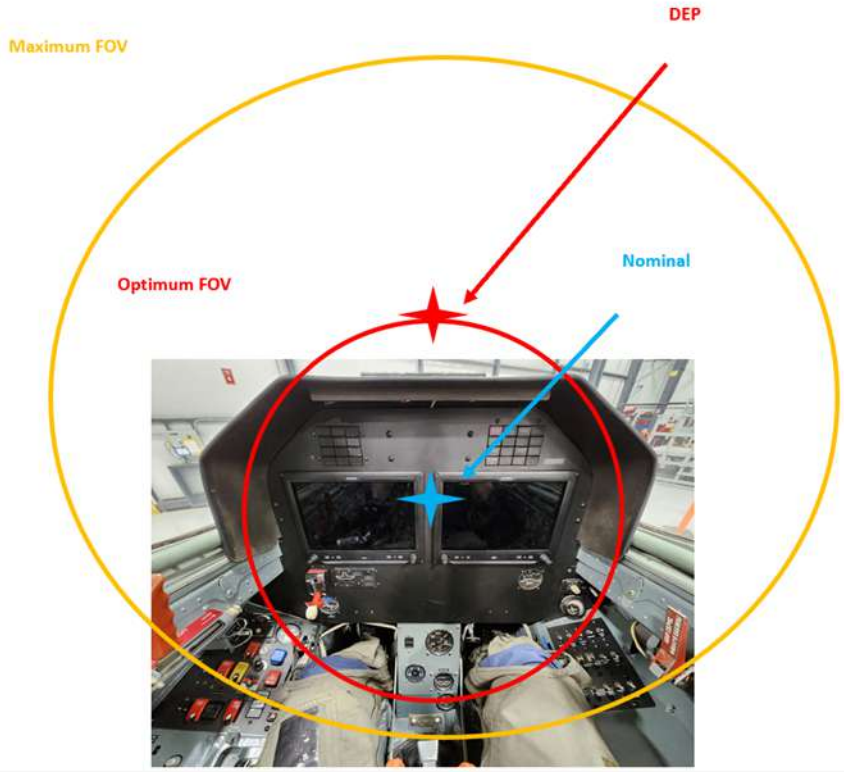


Figure 10: L39 Optimum and Maximum FOV Positions

Pilot's outside FOV was determined using smartphone (Dioptra application) for elevation and azimuth angles to plot AITOFF projection according to MIL-STD-850B [21]. Data process was given in Annex F.3.1. The viewing area in the front cockpit consisted of the transparent canopy and the front windshield, both were divided by a metal bow as shown in Figure 11.

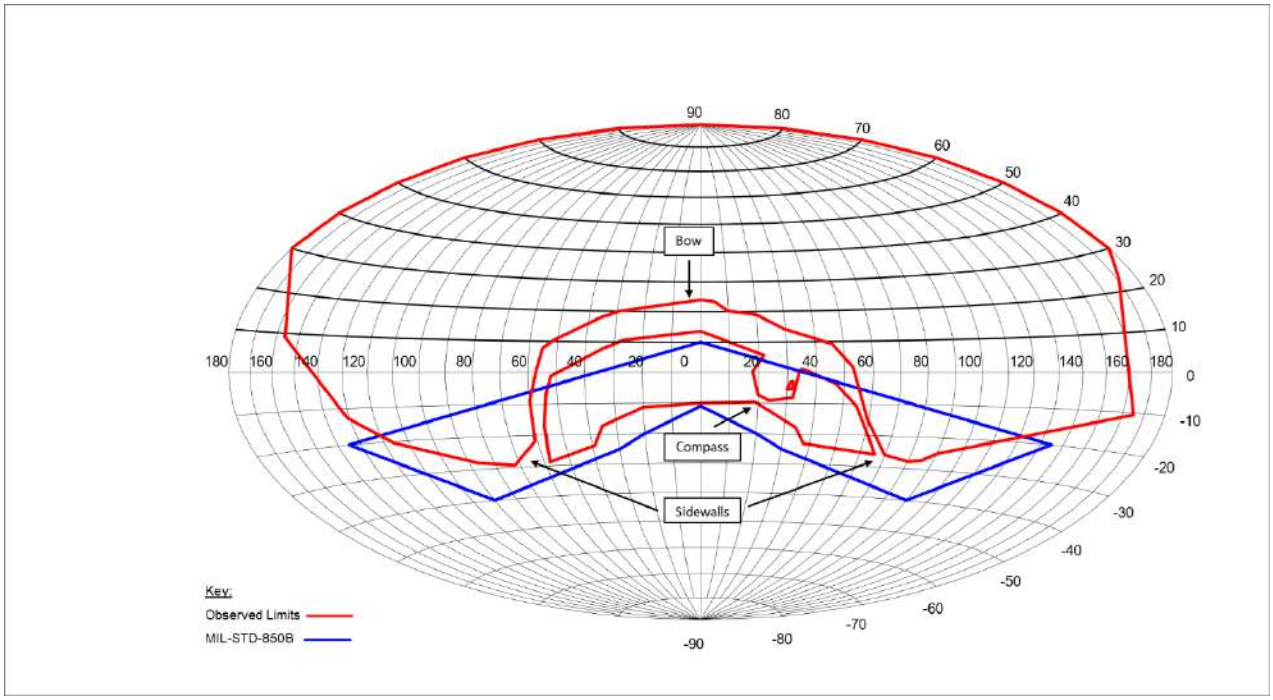


Figure 11: AITOFF Plot of Front Cockpit FOV

It was observed that the compass was located on 1 o'clock position which obstructed the outside view partially. The sidewalls of the cockpit were higher than standard. The aircraft provided an adequate surround view in front cockpit that was qualitatively commented by test pilot.

As BFM missions had the requirement of overwhelmingly outside look, primary displays which were gathered inside optimum FOV would give the chance to search and grab dedicated information at one glance as time in seconds would be important not to lose sight to adversary.

Outside view is of great importance during BFM training as the student pilots would use tactical maneuvers to deploy WEZ or employ their gun / missiles to bandit aircraft. When the dynamic atmosphere was considered, outside view should not be hindered by aircraft structure in order not to impact mission effectiveness. L39's bow, compass and relatively high sidewalls might be a disadvantage when thinking of transition to 5th aircraft which has bubble canopy innovations, L39 should be considered still competent to conduct effective BFM tasks due to its sufficient outside view. The focus was given to how many seconds those obstructions would hinder sight to adversary which was answered as few seconds that would not impact overall mission suitability.

L39's inside and outside FOV was assessed SATISFACTORY due to displays' position inside of optimum FOV and sufficient space found to be for outside FOV regarding AITOFF plot and qualitative evaluation of test pilot.

2.1.3 EFIS

Cockpit EFIS assessment was performed under the conditions of ground evaluation referring to ITPS Avionics Manual Glass Cockpits and Electronic Flight Information Systems [20] and AC 23.1311-1C Installation of Electronic Display in Part 23 Airplanes [3]. Test pilot, whose anthropometric data was given in Annex C.7, was worn of flight suit, boots, G suit, helmet, and kneepad.

In the front cockpit, aircraft was coated with two Garmin G3X GDU 460 (Annex C.3, C.4) wide screens that generally gave the test pilot the feeling of intuitiveness. Left hand side display basically worked as PFD comprise of primary instruments display and right-hand side worked as a MFD for additional avionics capabilities. Both screens had the feature of splitting into two, left hand side held the responsibility to always show primary instruments and right-hand side could generate multiple pages' display as a whole screen or map fixed on left part while right part could be rotary changeable during split screen feature activated. 9 subpages were observed which were MAP, CHT (enroute charts), WPT (waypoint), FPL (active FPL), WX (weather), TER (terrain), TRF (traffic), SXM (SiriusXM Audio - entertainment purpose), INFO (information - about GPS) and ENG (engine). Test pilot tried all pages and menu options, rotary and push buttons / knobs to monitor capabilities of the system (Figure 12).

Figure 12: Garmin G3X GDU 460 Displays Pilot View

Garmin G3X GDU 460 screens were observed to be sufficient by means of easiness, mistake imperviousness, low complexity of menu system, display size, resolution, update / refresh rate, declutter, labels, coherence among both displays and intuitiveness. Color codes were in line with AC 23.1311-1C [3] and coherent among warning / caution lights. There was no contrast adjustment selection through the menu options and brightness could be adjusted via sub menu pages without a discrete physical knob or button. Auto brightness function could be selected by pilot decision. It was evaluated that fuel level reading had a slight difficulty due to its value number size that was relatively small as shown in Figure 13.

Figure 13: Garmin G3X Fuel Level Reading

Summary of findings were listed below in Table 6.

Items	PFD / MFD
Display size	Sufficient
Color	Sufficient
Brightness (+adjustment)	Sufficient
Contrast (+adjustment)	N/A
Resolution, readability	Small fuel level value number
Update & refresh rate (zoom in / out)	Sufficient
Declutter	Sufficient
Controls / keyboard	Brightness could be reached via sub menus Sufficient
Labels	Sufficient
Alerts (aural, symbology)	N/A
Reflection	Was not tested
Electronic checklist	N/A
Coherence among displays (colors / symbols)	Sufficient

Table 6: Summary of Garmin G3X EFIS Evaluation

Regarding BFM mission task, a simulated area wanted to be drawn on MFD map page but G3X didn't have this feature. Instead of that, area was tried to draw via FPL and simulated working area boundaries could be illustrated by pseudo-FPL. FPL entry was assessed easy, fast to manipulate and intuitive. Due to its unsuitability of operation philosophy, test pilot couldn't tradeoff between area drawing and real FPL entry functionality.

There was a useful feature of Garmin G3X to give pilot an aural warning for preset barometric altitude as shown in Figure 14.

Figure 14: Garmin G3X Minimum Altitude Feature

Test pilot couldn't find any stores management system (SMS) related pages in Garmin G3X pages.

Due to COAF requirements mentioned in FTO [1] about recommendation display menu selection during BFM setups could be forged as primary instruments occupying whole screen for PFD, including G meter to put on right side of HSI and split screen comprise of map and traffic menus for MFD as depicted in Figure 15.

Figure 15: Best Solution of Display Menus of BFM Task

With this design of displays, student pilot could robust his / her situational awareness for 3D environment using primary instruments with their background on PFD and map on the right MFD. The rationale to keep PFD as a whole screen was to be able to get most critical data (primary instrument) by a wide screen presentation and to be able illustrate G meter (G meter couldn't be shown in split screen choice) to be aware of normal load factor during dynamic maneuvers. Map and traffic page on the right would give student pilot a 2D situational awareness and some clues for maintaining training area. On the other hand, traffic page could allow student pilots to monitor approaching intruder traffics with range scale increased. Furthermore, traffic page could help student pilot if he / she would decrease the range scale to minimums to monitor leader aircraft's position for estimation of lateral / vertical distance which could be useful for line abreast formation flight before setups' initiations. Additionally, student pilot could also use this function for distance estimation to employ air to air missiles or attack with gun. One more contribution could be given in case of lost wingman situations to rejoin by the cue introduced by traffic page. Engine parameters could be monitored any time from PFD / MFD right side wall.

Dynamic and high maneuver BFM missions would require maximum look out to observe bandit's maneuvers and adapt L39 aircraft spontaneously occurring new circumstances. A powerful avionics capability would help student pilot. Student pilots could only look inside few seconds and grab the prominent information from displays like airspeed, altitude, fuel reading, engine parameters, load factor etc. Altitude and airspeed dynamic flow should be very intuitive to be caught in a very short period. If the aircraft didn't have assistant features like altitude, minimum airspeed, limit normal load factor and predetermined fuel low alert, those readings would be of great importance. Hopefully, L39 would warn student pilot for approaching to floor (according to minimum altitude set feature mentioned in Garmin pilot's guide in (Annex C.5) that would be tested inflight tests, but considerations should be focused on low fuel (predetermined JOKER / BINGO).

Garmin G3X small fuel quantity reading in all pages was assessed UNSATISFACTORY (CLASS III).

A fuel low aural alert feature for pilot determined value should be added to software of Garmin G3X due to its difficulty in reading fuel quantity value in all pages (DESIRABLE - EFFECTIVENESS / SAFETY).

Display menu selection during BFM setups should be forged as primary instruments occupying whole screen for PFD, including G meter put on right side of HSI and split screen comprise of map and traffic menus for MFD (DESIRABLE - EFFECTIVENESS).

2.1.4 ACMI Debriefing Software

ACMI debriefing software was evaluated with the help of pre-saved mission data due to constraints mentioned in paragraph 1.6.

Data uploaded to SD card which was inside the housing of PFD / MFD was given below as:

- Airspeed in IAS, TAS, GS and Mach number, altitude, magnetic / true heading, normal load factor and OAT,
- Pitch, roll and yaw angles,
- Latitude and longitude information of GPS position,
- Engine and fuel parameters.

ACMI software could gather those data and fuse them to create valuable information like positioning two aircrafts over representative world, relative position parameters such as range, aspect angle, bearing and rate of closure to each other, position to a predetermined bullseye point etc. Software could generate 2D and 3D illustration of aircrafts by exploiting fused data as shown in Figure 16.

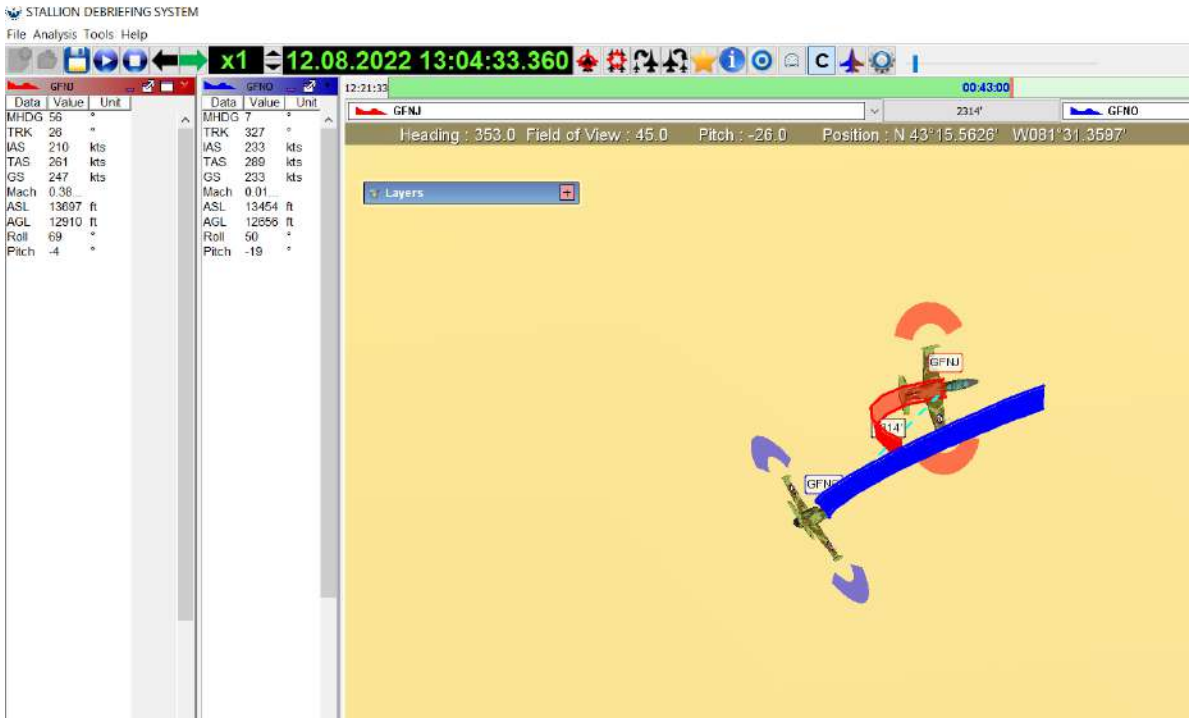


Figure 16: ACMI Debriefing 3D Demonstration

Besides 2D / 3D generation, software could create HUD view of the aircraft using core information derived from SD card as depicted in Figure 17.

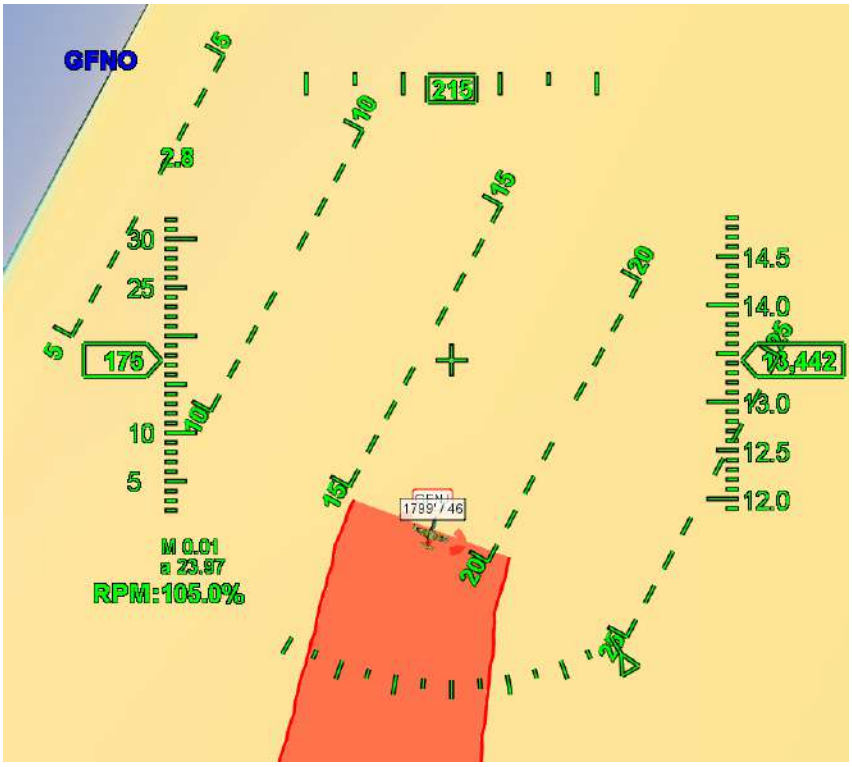


Figure 17: ACMI Debriefing HUD view

When the trigger squeezed during BFM setups, it was recorded as an event mark and during ACMI software run, it was seen as a gun / missile shot.

BFM missions would be difficult to understand by COAF student pilots because of its abstract nature. It would be of great importance to do an efficient reconstruction during flight debriefing. To execute a good debriefing, onboard cameras would not be so helpful as student pilots would need specific illustrations about what happened in the setups by means of aircraft motions and effectivity of those maneuvers considering 3D environment. ACMI software would promote student pilots' understanding to evolve BFM's vague nature to a more solid ground.

Student pilots could recognize their maneuver performance with the help of information like altitude loss during the execution of vertical maneuvers. They could see the amount of high / low yoyo maneuvers and they could clutch how much airspeed depleted or increased during that amount of maneuver. It would stand for like an FTI information which is valuable for flight test crew.

They would easily understand why the specific tactic didn't work as they could compare airspeed, turn rate, turn radius, load factor between the adversary aircraft and his / hers. They could also be aware of the exact ranges (considering they would use L39 gun sight reticle or traffic page of MFD) at their gun / missile shots and could evaluate if those shots were valid or not. Next time they could calibrate their cues considering they would have lesson learns from

ACMI debriefing. Even a very simple 3D debriefing system would be very helpful to COAF student pilots as ACMI debriefing had more than basic data.

Within the scope of the test, ACMI debriefing software capabilities was assessed SATISFACTORY due to significant effect to increase BFM training efficiency.

2.2 Stall Speed Determination and Stall Characteristics

Stall tests, TP 2.1, 2.2, 3.20, 3.21 and 3.22, were flown in first and second sortie. Stall speed determination and stall characteristic test techniques as per ITPS Stall Speeds Manual [8] and ITPS Stall Characteristics and Spinning Manual [18] was used to determine stall speed / characteristics. Test conditions were given below in Table 7.

TP#	Test Description	V_T (KIAS)	Altitude (ft)	Thrust (RPM)	A/C Weight (lb)
2.1 / 2.2 / 3.20	Stall controllability / performance / characteristics wings level, idle, unaccelerated	142	8200	56.6%	9882
3.21	Stall characteristics 30° bank, idle, unaccelerated	150	8400	56.5%	8638
3.22	Stall characteristics 30° bank, 75% MCP, accelerated	148	8000	94%	8532

Table 7: Test Conditions of Stall

Due to time constraint and having the chance to test a certified airplane, stall tests were combined to be performed as performance and characteristics at altitude of 8000 ft MSL.

Aircraft was trimmed at 1.4Vs (~140 KIAS) to perform controllability check (TP2.1) prior to wings level, idle, unaccelerated test. The effectiveness of controls was checked through 1.4 V_S to 1.1 V_S. Despite the slight lag in yaw and roll at low speed near 1.1 V_S, overall controllability satisfied test pilot. Then, stall speed determination and stall characteristic tests (TP2.2 / 3.20) was done during aircraft deceleration at a rate of 0.625 kts/sec from 1.1 V_S (110 KIAS) with starting stopwatch until the aircraft stalled.

To perform TP 3.21 (30° bank, idle and unaccelerated), aircraft was trimmed at 1.4Vs (~150 KIAS) and then, test pilot banked left to 30° and reduced airspeed about 1 kt/sec to reach stall. Bleed rate was calculated with stopwatch by hack from 1.1Vs to stall. Test point could be repeated for right as well.

TP 3.22 (30° bank, 75% MCP and accelerated) was performed with trimmed aircraft at 1.4Vs (~150 KIAS) and then, test pilot banked left to 30° and reduced airspeed at 3-5 kts/sec to reach stall. Bleed rate was calculated with stopwatch by hack from 1.1Vs to stall. Test point couldn't be repeated to right due to limited time derived from operator.

Test results were shown below in Table 8.

TP#	Buffet SPD (KIAS)	Stall SPD (KIAS)	Δ ALT (ft)	Bleed Rate (kts/sec)	Bank	Pitch	Yaw
2.1 / 2.2 / 3.20	110	99	400	0.625	10° right	-5°	-
3.21 Left	111	100	1180	1.11	+10° left	-4°	-
3.21 Right	105	96	950	0.67	+10° right	-4°	-
3.22 Left	110	57	1500	4.6	+30° left	-12°	-

Table 8: Test Results of Stall

Wings level, idle, unaccelerated stall speed was determined as 99 KIAS. Bleed rate was determined 0.625 kt/sec that was in the tolerance limit (below 1 kt/sec). Test stall speed was corrected for reference aircraft weight (9920 lb) to be 99.2 KIAS. Stall speed for standard aircraft weight (9920 lb / 4500 kg) was found to be 102.6 KIAS (190 km/h) as shown in Figure 18 derived from L39 AFM (Annex A.1).

Configuration		Without stores		With stores	
A/C Gross Weight		3,700	4,500	4,600	4,700
Flaps deflection LG position	0°, retracted	172	190	196	198
	25°, extended	157	173	182	184
	44°, extended	148	163	174	176

Figure 18: L39 AFM Stall Speeds

According to test result, wings level, idle, unaccelerated stall speed for test condition, 9882 lb, clean configuration, was 3.4% lower than the AFM data. That was in the acceptance margin of 10% which was mandated by COAF.

Wings level, idle, unaccelerated stall (departure) was characterized by slight airframe buffet following graduate airspeed loss and consequent nose down pith motion (-5°). Wing drop was

observed 10º bank to the right. Full controllability during stall was typical for the aircraft. Wing drop was easily corrected by ailerons, no rudder inputs were necessary. Recovery was easy and almost immediate after stick releasing with the height loss of 400 ft. No pitch up tendency was exposed.

Right and left 30° bank, idle, unaccelerated stalls demonstrated very close to or lower than 99 KIAS which were 100 KIAS and 96 KIAS respectively interpreted inconsistent while 30° bank would have created [$Vs * (1/cos\Phi)^{\frac{1}{2}}$] airspeed which would be 106.4 KIAS.

Left 30° bank, 75% MCP, accelerated stall demonstrated airspeed well below left 30° bank, idle, unaccelerated stall which would be a good margin during dynamic maneuvers.

In unaccelerated stalls, airplane did not exhibit rolling, yawing or downward pitching at the stall which couldn't be controlled to stay within 30 degrees.

During 30° bank, idle, unaccelerated stalls, aircraft showed an additional 10° bank to respective side and nose down motions were -4°. Characteristics were typical to wings level, idle, unaccelerated stall.

During 30° bank, 75% MCP, accelerated stall, aircraft showed an additional 30° bank to respective side and nose down motion was -12°. Characteristics were typical to wings level, idle, unaccelerated stall.

Stall warning feature of L39 showed itself as buffet that was inside 1.05Vs to 1.15Vs among all tested unaccelerated versions.

During BFM training, COAF should determine a safe minimum airspeed that would hinder aircraft from abnormal attitudes which could conclude as departures or spins, besides, this minimum airspeed should also hinder impacts to mission effectiveness in order not to be too conservative. LIFT student pilots would select 1.1Vs stall airspeed as minimum to be on the safe side while maneuvering their aircrafts. It would be obvious that BFM training would be susceptible to dynamic and powered stalls, 1.1 times of wings level, idle, unaccelerated stall speed could protect them from stalls as powered stall speeds would be much lower than this one. Sometimes, COAF would require conducting DACT (dissimilar aircraft combat maneuvers) which could be a lower speed adversary that would force LIFT student pilots to fly at lower speeds. In this case, determined minimum safe airspeed would protect student pilots again and they would learn how to use geometry with maximum available thrust to establish, keep and not to overshoot WEZ (weapon employment zone).

On the other hand, benign stall characteristics would always help LIFT student pilots in the consequences of unintentional departures that they could easily recover the airplane and contribute to flight safety. In addition to that, benign stall characteristics would always encourage student pilots and their instructors to use aircraft's speed and maneuver envelope boundaries to be able conduct BFM setups effectively and closest to real war scenarios. Otherwise, they

would hesitate to do courageous maneuvers that would not be realistic and hinder improvement of student pilots.

L39's stall performance having 3.4% stall speed deviation from AFM data, aircraft's sufficient stall approach indications, benign stall characteristics and easy recovery feature were assessed SATISFACTORY.

Further testing should be done with onboard FTI to comply with paragraph 3.4.2.1.1.2 of MIL-F-8785C [5] which was warning range for accelerated stalls (DESIRABLE - EFFECTIVENESS).

L39 aircraft demonstrated Level 1 class IV aircraft stall characteristics according to paragraph 3.4.2.1.1 of MIL-F-8785C [5], in that, stall approach shall be accompanied by an easily perceptible warning consisting of shaking of the cockpit controls, buffeting, or shaking of the airplane, or a combination of both.

L39 aircraft demonstrated Level 1 class IV aircraft stall characteristics according to paragraph 3.4.2.1.1.1 of MIL-F-8785C [5], in that, warning onset for stalls at 1 G normal to the flight path shall occur between minimum speed for onset higher of 1.05Vs or Vs + 5 knots and maximum speed for onset higher of 1.15Vs or Vs + 1.5 knots.

L39 aircraft demonstrated Level 1 class IV aircraft stall characteristics according to paragraph 3.4.2.1.2 of MIL-F-8785C [5], in that, in the unaccelerated stalls, the airplane shall not exhibit rolling, yawing or downward pitching at the stall which cannot be controlled to stay within 30 degrees for class IV airplanes and it is desired that no pitch up tendencies occur in unaccelerated or accelerated stalls.

L39 aircraft demonstrated Level 1 class IV aircraft stall characteristics according to paragraph 3.4.2.1.3 of MIL-F-8785C [5], in that, it shall be possible to recover from a stall by simple use of the pitch, roll and yaw control with cockpit control forces.

2.3 Performance Evaluation

2.3.1 Climb Performance

Climb performance test point 2.3 was flown in second sortie by implementing test techniques as per ITPS Climb and Descent Performance Manual [9] for assessment. Test conditions were given below in Table 9.

TP#	Test Description	V_T (KIAS)	Altitude (ft)	Thrust (RPM)	A/C Weight (lb)
2.3	Level Acceleration	106	13 000	103%	9603

Table 9: Test Conditions of Level Acceleration

Aircraft was accelerated in level flight from $1.1V_S$ to maximum airspeed in level flight with maximum continuous thrust (V_H) at 13 000 ft MSL. Excess thrust of aircraft was derived by airspeed change. Acceleration was continued until reaching speed increment of 2 kts per 10 seconds. Every 10 seconds, airspeed, altitude, OAT, engine RPM parameters were recorded by hand. Collected data was introduced in Annex F.2, Table 37.

Test was started from 110 KIAS (1.1 V_S) and ended at 310 KIAS. Total acceleration time was 220 seconds. Test conditions were corrected for 4000 m (13 123 ft MSL), 9800 lb (4400 kg) standard weight and ISA. Data reduction (Annex F.3.2) was implemented to fit 3rd order polynomial curve to determine best rate of climb and speed as found 203.0 KIAS and 2479.2 ft/min respectively. According to AFM (Annex A.1), best rate of climb and speed were found 207.2 KIAS (383 km/h) and 2500.0 ft/min (25 km for 3.7 min equates 0.762 km/min) at 13 123 ft MSL for 9800 lb standard weight, 0 drag index and ISA conditions as shown in Figure 19 and Figure 20.

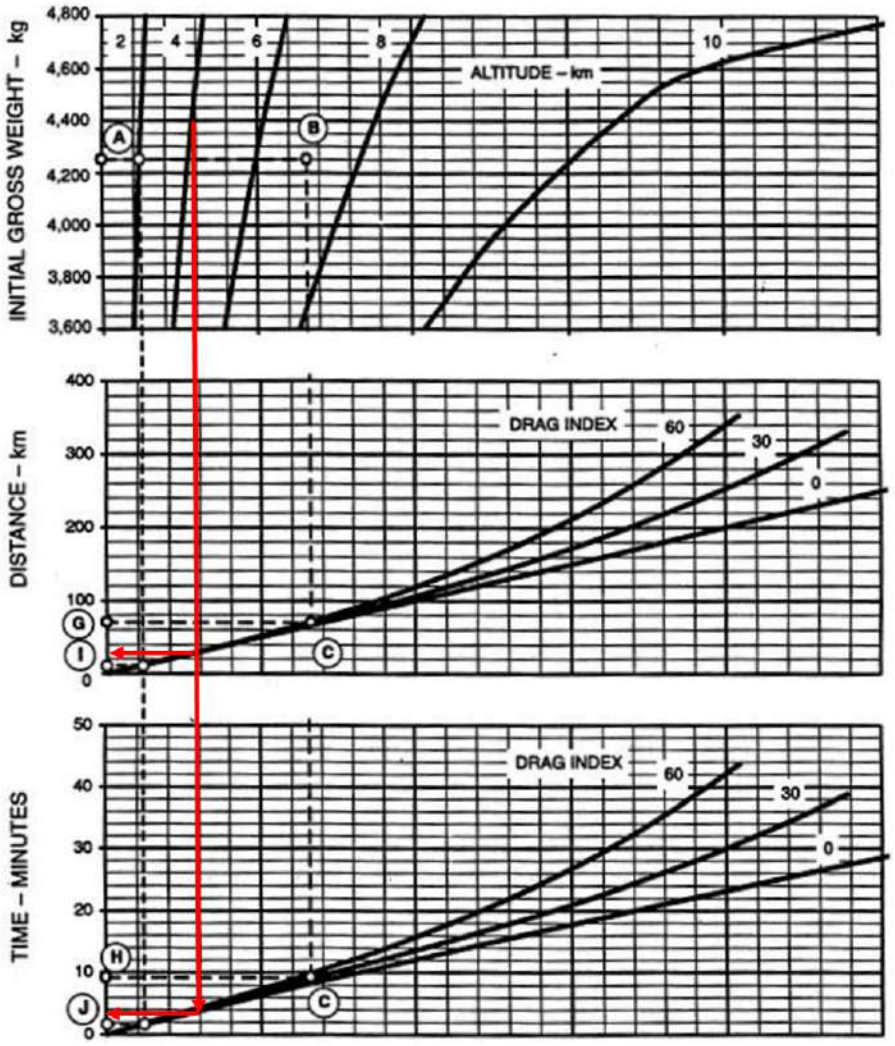


Figure 19: AFM Best Rate of Climb Distance and Time

OPTIMUM CLIMB SPEED – km/h			
	DRAG INDEX		
ALTITUDE [km]	0	30	60
0	430	392	368
2	415	380	359
4	383	364	345
6	361	344	328
8	337	329	315
10	310	304	291

Figure 20: AFM Best Rate of Climb Airspeed

Best rate of climb and speed comparison between test results and AFM results were illustrated in Figure 21.

Description	Level Acceleration	Test Point #	2.3
Aircraft	L39	A/C Registration	CGFNO
Date	23 NOV 2022	OAT	-9 °C
Altitude	13 000 ft	CG	23.7%
Weight	9603 lb	Config.	Clean / Cruise
Thrust	103%		

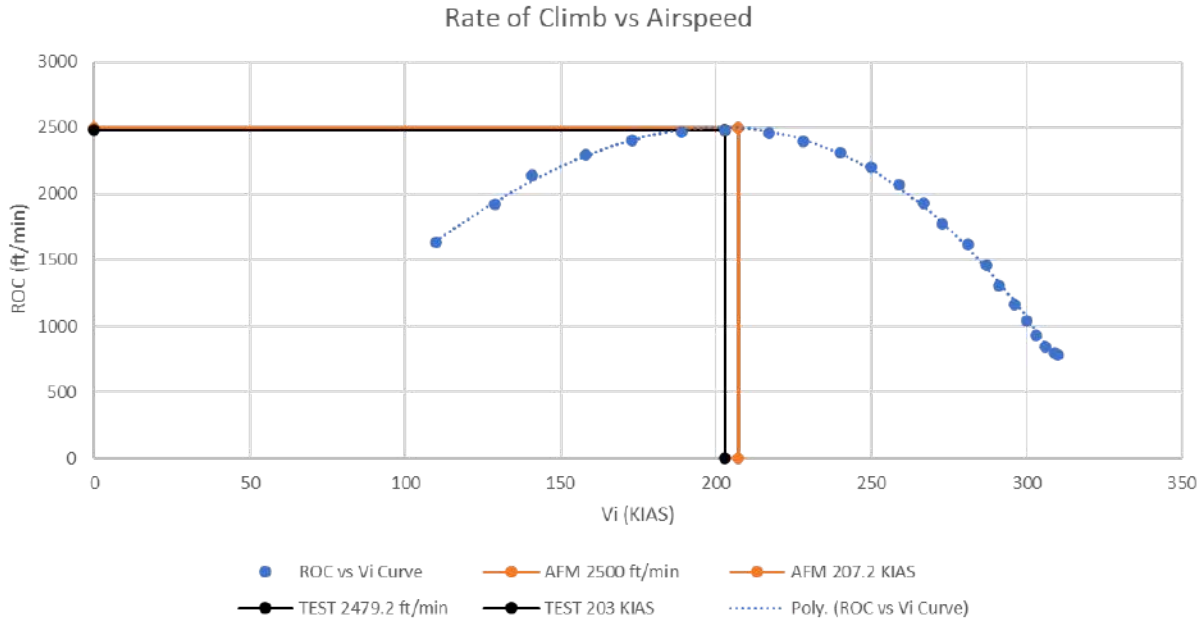


Figure 21: Best Rate of Climb and Speed Comparison with AFM

According to test result, best rate of climb speed was 2.0% lower and best rate of climb was 0.8% lower than AFM data for 9800 lb standard weight, 0 drag index, clean configuration, and ISA. Those differences were in the acceptance margin of 10% which was mandated by COAF.

Best rate of climb parameters would be useful to COAF student pilots to determine how many setups could be executed for mission planning considerations. Besides, maintaining those parameters after setup termination to climb up to initial setup altitude would contribute efficiency by means of fuel consumption. As BFM missions were high energy tasks, depleting fuel in a fast pace, every effort should be given to time outside between fights on and terminate. As student pilots would know the best rate of climb time, fuel consumption and maintaining best rate of climb airspeed might lead to earn one more setup for training or might hinder them to lose one setup which could impact their training progress as missions' effectiveness would occur in a very short time and would be valuable in order not to miss any minute.

L39 was assessed SATISFACTORY for intended LIFT mission with 2% acceptable deviation in best rate of climb speed and 0.8% acceptable deviation in best rate of climb comparing to AFM data.

2.3.2 Maneuver Performance

Maneuver performance test points 2.4, 2.5 and 2.6 were flown in second sortie by implementing test techniques as per ITPS Maneuver Performance Manual [10] for assessment. Test conditions were given below in Table 10.

TP#	Test Description	V_T (KIAS)	Altitude (ft)	Thrust (RPM)	A/C Weight (lb)
2.4	Stabilized Turn Front Side	306	13 000	103%	9337
2.5	Stabilized Turn Back Side	202	12 900	103%	9125
	Stabilized Turn Back Side	180	13 040	103%	9125
	Stabilized Turn Back Side	160	12 960	103%	9125
	Stabilized Turn Back Side	142	12 880	103%	9125
2.6	Wind Up Turn	252	13 800	103%	8895
	Wind Up Turn	233	13 600	103%	8895
	Wind Up Turn	210	13 500	103%	8895
	Wind Up Turn	188	13 200	103%	8895
	Wind Up Turn	172	12 800	103%	8895

Table 10: Test Conditions of Maneuver Performance

Front and back side steady turn test techniques were used to determine sustained turn performance. In front side FTT, four different target load factor conditions were performed due to reaching aircraft limit. Aircraft was slightly descended from 13 200 ft MSL and established V_H (~ 306 KIAS) at around 13 000 ft MSL with %103 engine RPM. When stable condition was established with bank angle or normal load factor for minimum 5 seconds, airspeed, load factor, angle of bank, altitude, engine RPM, stick force and fuel parameters were recorded by hand (Annex F.2, Table 38).

In back side FTT, four different target airspeed conditions were performed. Aircraft was stabilized at 202 KIAS, 12 900 ft MSL, then, was rolled into turn whilst increasing thrust to %103 RPM while maintaining target airspeed for minimum 5 seconds. Airspeed, load factor, angle of bank, altitude, engine RPM, stick force and fuel parameters were recorded by hand (Annex F.2, Table 38).

After implementing data reduction (Annex F.3.3), test results were corrected to weight of 4400 kg (9800 lb) and altitude of 4000 m (13 123 ft MSL) and calculated as shown in Table 11.

	Maximum Sustained Turn Rate (deg/sec)	Maximum Sustained Turn Rate Airspeed (KTAS)	Minimum Sustained Turn Radius (deg/sec)	Minimum Sustained Turn Radius Airspeed (KTAS)
Test Data	8.3	232	2200	183
AFM Data	8.5	227.2	2000	170
Difference	-2.5%	2.1%	10.0%	7.6%

Table 11: Test Results of Sustained Turn Performance

Wind up turn test technique was used to determine instantaneous turn performance. Five different target airspeed conditions were performed. Aircraft was stabilized at 252 KIAS, 13 800 ft MSL, then engine RPM was set to %103. Aircraft started bank and maintained target airspeed via increasing N_Z and exploiting climb or descent until stall buffet / wing rock / uncontrollable flight path achieved within data band. Airspeed, load factor, angle of bank, altitude, engine RPM, stick force and fuel parameters were recorded by hand. Test data was presented in Annex F.2, Table 38.

After implementing data reduction (Annex F.3.3), test results were corrected to weight of 4400 kg (9800 lb) and altitude of 4000 m (13 123 ft MSL) and calculated as shown in Table 12.

	Maximum Instantaneous Turn Rate (deg/sec)	Maximum Instantaneous Turn Rate Airspeed (KTAS)	Minimum Instantaneous Turn Radius (deg/sec)	Minimum Instantaneous Turn Radius Airspeed (KTAS)
Test Data	14.3	317	1900	240
AFM Data	14.9	317	1800	220
Difference	-4.3%	0.0%	5.6%	9.1%

Table 12: Test Results of Instantaneous Turn Performance

Doghouse (Figure 22) was plotted to illustrate AFM and test results for sustained and instantaneous turn performance. Test results were integrated into the graphic via 2nd order polynomial fit as introduced in Annex F.3.3.

Description	Maneuver Performance	Test Point #	2.4. 2.5, 2.6
Aircraft	L39	A/C Registration	CGFNO
Date	23 NOV 2022	OAT	-9 °C
Altitude	13 000 ft	CG	23.3%
Weight	9337-8895 lb	Config.	Clean / Cruise
Thrust	103%		

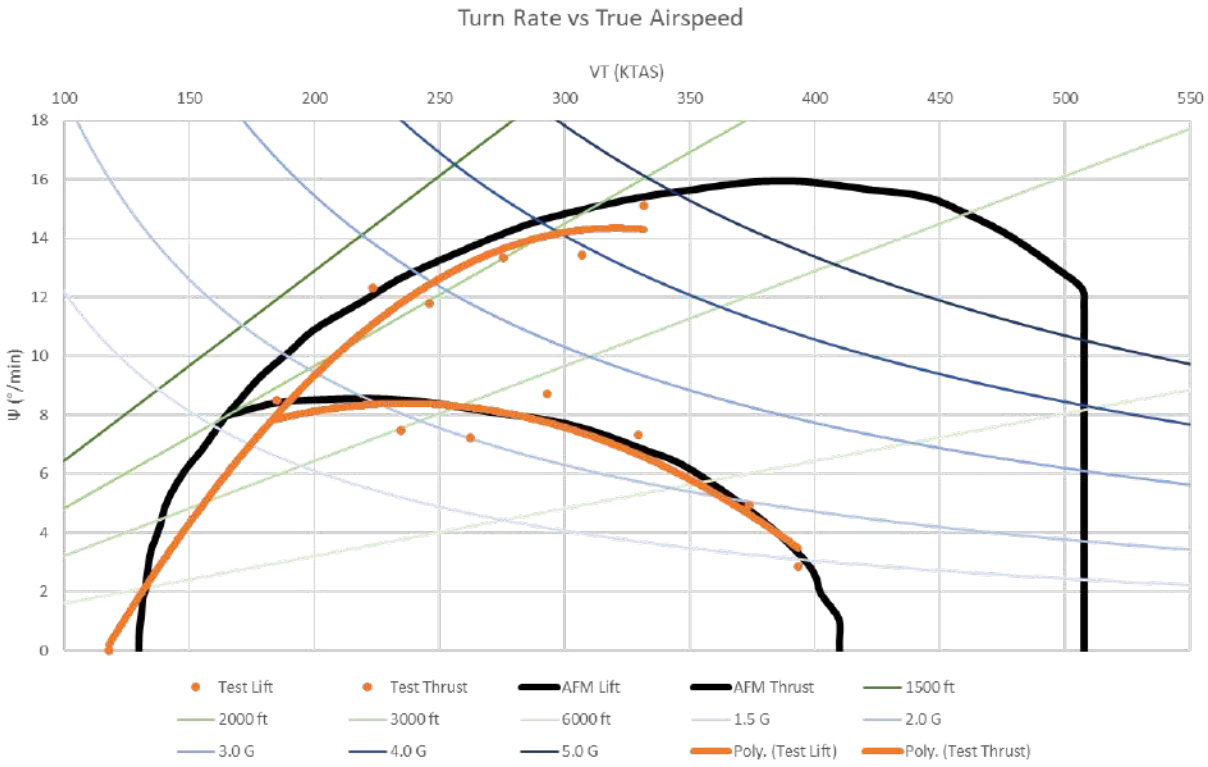


Figure 22: Doghouse Comparison of Test and AFM

Maneuver performance key parameters of rate and radius fight were compared through test results and concluded as all sustained / instantaneous maximum turn rate and minimum turn radius with their speeds were equal to or below 10% deviation which was mandated by COAF.

BFM training could be conducted either with similar and dissimilar aircrafts or same aircrafts simulating different performances like thrust limited or turn limited. A comprehensive preparedness of key performance parameters of L39 and opposing aircraft would gift the student pilot to win the fight and understand the dynamics of air combat training.

In air combat training, student pilot would consider for adversary's instantaneous / sustained maximum turn rate and minimum turn radius performance. As he / she would know about maneuver performance values of both his / her aircraft and bandit's, he / she would pick the chance of two circle fight if his / her own aircraft's maximum turn rate performance was better than the bandit. If L39's minimum turn radius performance was better than the adversary, then, he / she would pick the chance of one circle fight.

It would be also helpful to know the turn radius of L39 to select the exact position according to adversary about entering TC (turn circle). Normally student pilots would prefer to be on turn circle of L39 to get advantage of fight. In case of spontaneous occurring situations of being inside or outside TC, student pilot would adapt his position via effective tactics if he could know turn radius of his / her aircraft and determine it.

L39's maneuver performance was assessed as SATISFACTORY comparing with its AFM to be inside limit of 10%.

2.3 Flying Qualities Evaluation

2.4.1 FCMC and Longitudinal Static Stability

FCMC and LSS tests, TP 3.1, 3.2 and 3.3, were flown in first sortie by implementing test techniques as per ITPS FCMC Manual [11] and ITPS LSS Manual [12] for assessment. Test conditions were given below in Table 13.

TP#	Test Description	V_T (KIAS)	Altitude (ft)	Thrust (RPM)	A/C Weight (lb)
3.1	FCMC 140 KIAS	140	8040	88.4%	9838
3.2	LSS 140 KIAS	141	8060	88.4%	9696
3.3	FCMC / LSS 200 KIAS	202	7960	88.5%	9307

Table 13: Test Conditions of FCMC and LSS

Once the aircraft was trimmed in the test conditions, pilot qualitatively evaluated the flight control mechanical characteristics in terms of free play, breakout, and centering for pitch, roll and yaw. Then, stabilized method was performed where the pilot applied pull force to reduce the speed to $0.85V_T$ (120 / 170 KIAS respectively for 140 / 200 KIAS) below the trim airspeed in the deceleration part, and increased airspeed to $1.15V_T$ (160 / 230 KIAS respectively for 140 / 200 KIAS) above the trim airspeed in the acceleration part. Stick force data was gathered at every 10 knots by hand feel (Annex F.2, Table 39). Data reduction was introduced in Annex F.3.4.

It was observed that longitudinal flight controls had absolute centering and no free play. Breakout and friction forces were compared to MIL-F-8785C limits as shown in Table 14.

Pitch MIL-F-8785C Min. / Max. (lbf)	Pitch Test (lbf)	Roll MIL-F-8785C Min. / Max. (lbf)	Roll Test (lbf)	Yaw MIL-F-8785C Min. / Max. (lbf)	Yaw Test (lbf)
0.5 / 3	1	0.5 / 2	1	1 / 7	2

Table 14: Test Results Comparison of FCMC to MIL-F-8785C

Breakout / friction forces were depicted in Figure 23 for pitch control of stick. As stick force was evaluated qualitatively and return speed forces were too close to previous ones, discrimination between breakout and friction forces wasn't applied to graph.

Description	FCMC 140 / 200 KIAS	Test Point #	3.1, 3.3
Aircraft	L39	A/C Registration	CGFNO
Date	22 NOV 2022	OAT	0 °C
Altitude	8000 ft	CG	23.0%-22.7%
Weight	9838-9307 lb	Config.	Clean / Cruise

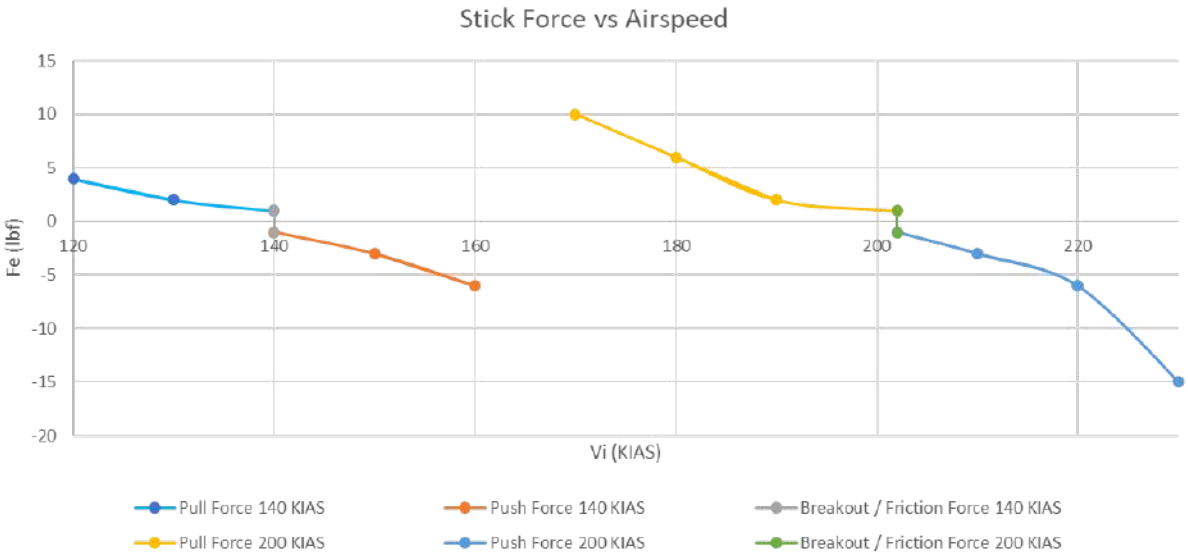


Figure 23: Breakout / Friction Forces

It was evaluated that the aircraft had apparent static stability that required push force for airspeeds above the trim airspeed and pull force for airspeeds below the trim airspeed with a stable stick force curve slope for all test points. It was observed that in all tested conditions, required push force was higher than the pull force for the same speed change from the trim position. Even though stick force slopes were relatively low, stick force varied linearly with the airspeed change and it was perceptible to the pilot. There was no non-linearity, lightening or reversals in the stick forces and stick displacements. Test results are given in Table 15 in terms of stick force curve slopes and FRSR for both push and pull directions.

TP#	V_i (KIAS)	Stick Force Curve Slope [lbf/kts]		FRSR (%)	
		AFT	FWD	AFT	FWD
3.2	141	0.2	0.3	-0.02	-0.02
3.3	202	0.3	0.5	-0.01	0

Table 15: Test Results of LSS

Stick force per airspeed data were illustrated in Figure 24 by implementing second order polynomial. Free return speed ranges were also depicted.

Description	LSS 140 / 200 KIAS	Test Point #	3.2, 3.3
Aircraft	L39	A/C Registration	CGFNO
Date	22 NOV 2022	OAT	0 °C
Altitude	8000 ft	CG	22.9%-22.7%
Weight	9696-9307 lb	Config.	Clean / Cruise

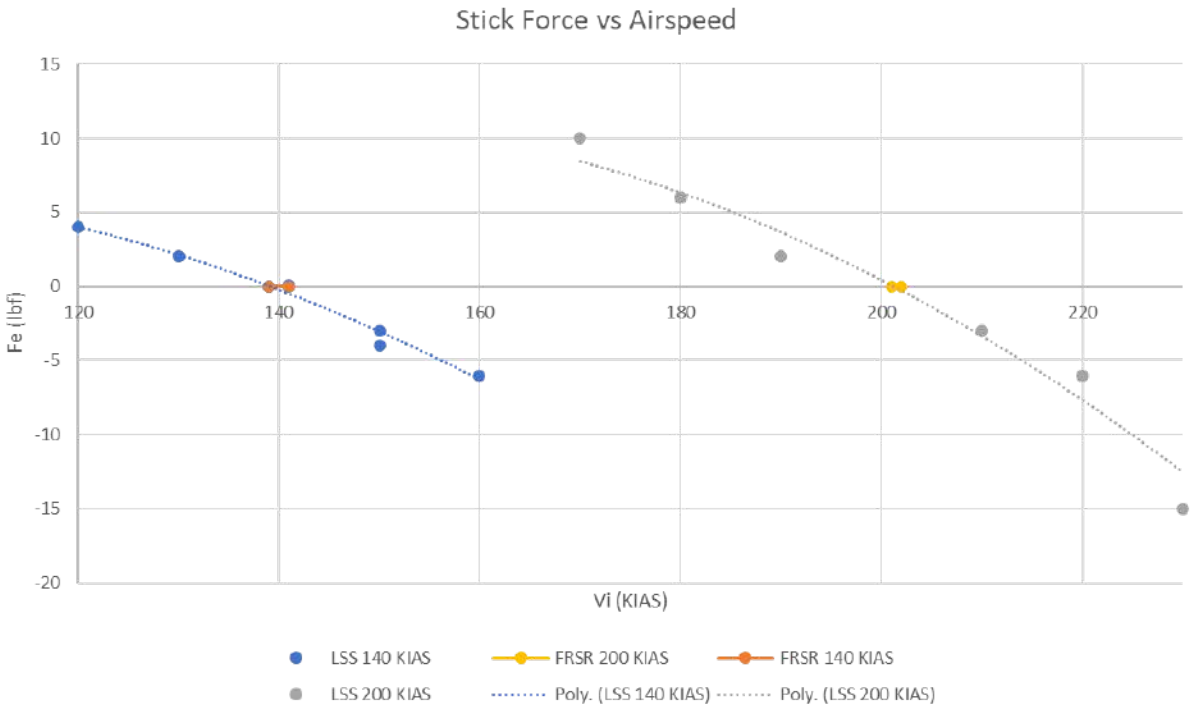


Figure 24: LSS Forces and FRSR

The low breakout forces, low friction band and control centering characteristics of L39 would allow student pilots to command and trim the aircraft precisely and preclude inadvertent stick inputs and poor control. It would be prominent during formation flights as poor control or very sensitive stick would lead student pilots to encounter PIO and might conclude with inadvertent mid-air collision or abandoning formation flight task.

The low free return speed ranges and stable stick force curves of L39 would allow student pilots to easily establish the trimmed condition and identify any deviation from that trimmed condition by the stick force. Thus, the student pilots of COAF would have spare capacity to focus on outside to monitor adversary aircraft especially at the initial phase of the setups as BFM setups would overwhelmingly require adversary monitor. Student pilots could easily focus on lead aircraft without any concern of stick movements as L39 would hinder inadvertent inputs to the stick because it would react by force.

L39's longitudinal static stability was assessed SATISFACTORY with perceptible forces and stable force curves.

Further testing should be done with onboard FTI to discriminate breakout and friction forces (DESIRABLE - EFFECTIVENESS).

Further testing should be done to comply with dynamic characteristics and damping of control systems, characteristics of secondary control systems and pitch control force variations during rapid speed changes, paragraphs 3.5.3, 3.5.3.1, 3.6 and 3.2.1.1.2 of MIL-F-8785C [5] (DESIRABLE - EFFECTIVENESS).

L39 was determined as Level 1 according to paragraphs 3.5.2.1, 3.5.2.2 and 3.2.1.1 of MIL-F-8785C [5] as the stick forces varied with the airspeed changes with a stable slope, free return speed ranges were low and breakout friction forces were inside limits.

2.4.2 Longitudinal Dynamic Stability

LDS tests, TP 3.4 through 3.9, were flown in first sortie by implementing test techniques as per ITPS LDS Manual [14] for assessment. Test conditions were given below in Table 16.

TP#	Test Description	V_T (KIAS)	Altitude (ft)	Thrust (RPM)	A/C Weight (lb)
3.5	SPO Doublet 140 KIAS	140	8100	88.6%	8865
3.7	SPO Doublet 200 KIAS	201	7940	88.6%	8988
3.8	Phugoid 140 KIAS	200	8120	88.6%	8829
3.9	Phugoid 200 KIAS	200	7880	88.6%	8927

Table 16: Test Conditions of LDS

Once the aircraft was trimmed in SPO test conditions, test pilot performed the frequency sweeps (TP 3.4, 3.6) to find the natural frequency. After determining natural frequency, test pilot conducted doublets for stick fixed and stick free. It was evaluated that the short period modes were deadbeat in all tested airspeeds regardless of controls fixed or free. There were no overshoots when the controls were released at out-of-phase condition. It was also commented that there was no flutter sensibility.

Once the aircraft was trimmed at phugoid test conditions, pilot reduced the airspeed 15% below the trim airspeed (120 / 170 KIAS respectively for 140 / 200 KIAS) by using pitch control only and then released the stick for controls free evaluation. Tests were not repeated for controls fixed as the elevator (stick) floating was not observed during the oscillations. Data was gathered by hand in terms of time, airspeed, and altitude change at each half cycle (Annex F.2, Table 40). Phugoid mode was allowed for 4 cycles in each test point for data recording.

With the collected data, damping ratio, natural and damped frequencies and periods were calculated by modelling the test data using the general 2nd order dynamic system free response equation given in Annex F.3.5. Phugoid mode results were given in Table 17.

TP#	V_i (KIAS)	ζ	ω_n (rad/s)	ω_d (rad/s)	T (sec)
3.8	140	0.26	0.15	0.14	44
3.9	200	0.18	0.11	0.10	61

Table 17: Test Results of Phugoid

It was assessed that the long period modes were convergent for both airspeeds. Results of 140 KIAS and 200 KIAS phugoid modes were illustrated in Figure 25 and Figure 26.

Description	Phugoid 140 KIAS	Test Point #	3.8
Aircraft	L39	A/C Registration	CGFNO
Date	22 NOV 2022	OAT	0 °C
Altitude	8000 ft	CG	22.6%
Weight	8829 lb	Config.	Clean / Cruise

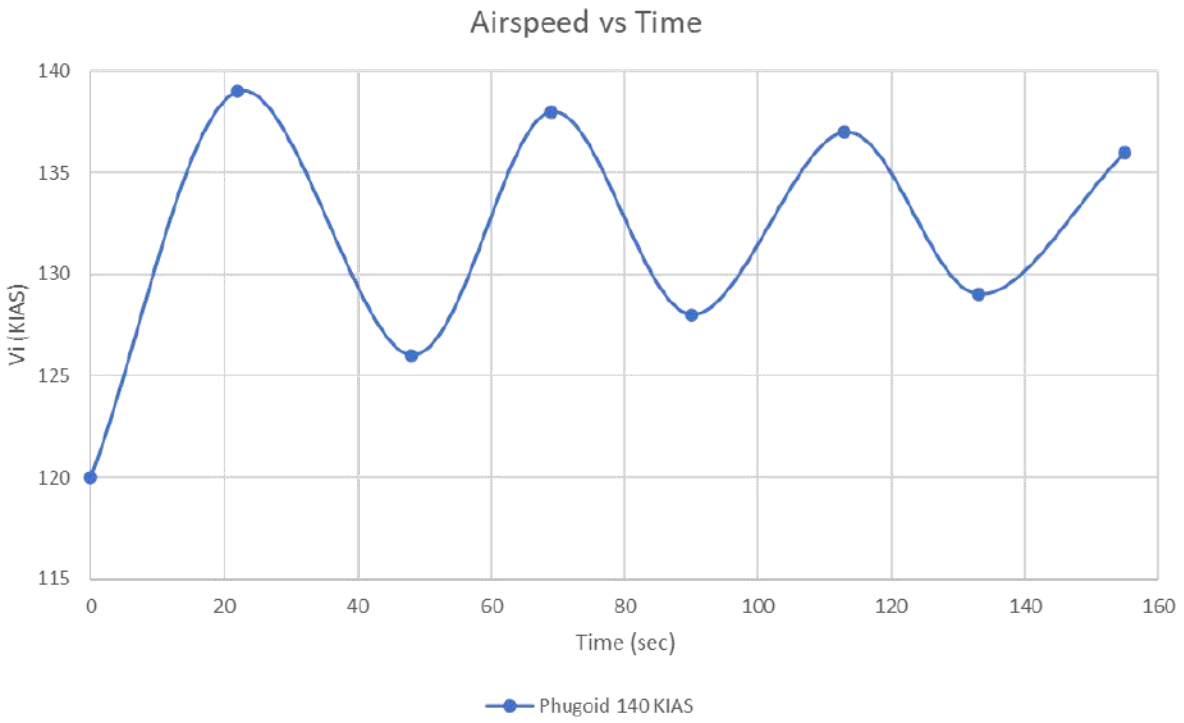


Figure 25: Phugoid 140 KIAS

Description	Phugoid 200 KIAS	Test Point #	3.9
Aircraft	L39	A/C Registration	CGFNO
Date	22 NOV 2022	OAT	0 °C
Altitude	8000 ft	CG	22.7%
Weight	8927 lb	Config.	Clean / Cruise

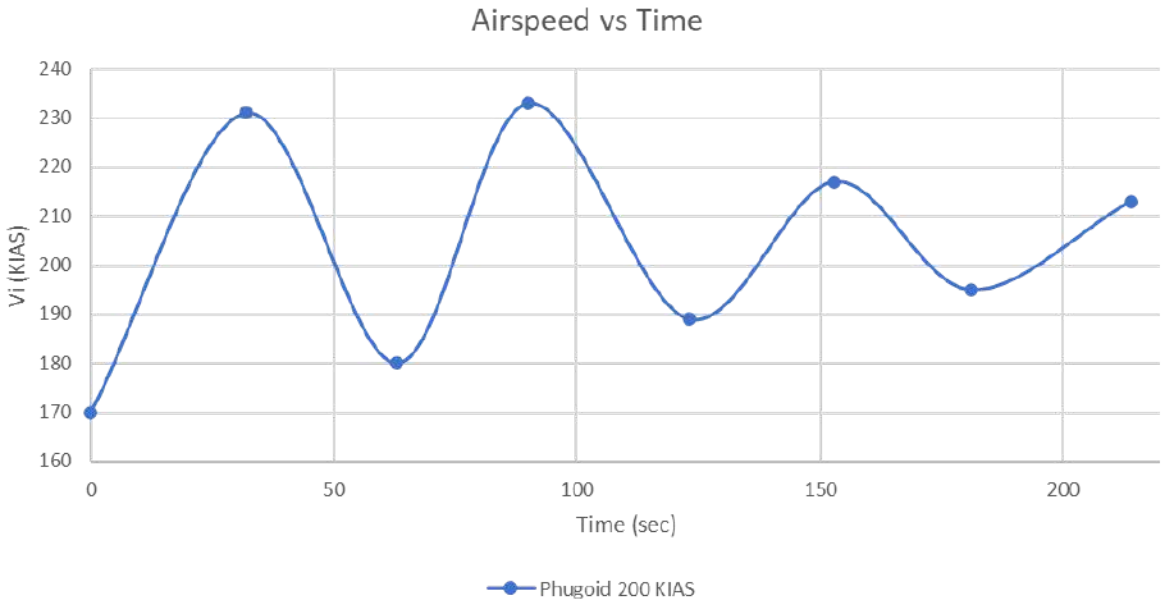


Figure 26: Phugoid 200 KIAS

Even though low damping ratios were observed, it was evaluated that the convergent phugoid modes did not create any dangerous characteristics as the aircraft's responses were mild and period was long enough (44 and 61 seconds for 140 and 200 KIAS respectively) to capture pilot's attention. Besides, damping ratio was found to be over Level 1 minimum limit (0.04) of MIL-F-8785C [5].

The heavily damped (deadbeat) short period mode characteristics of L39 would not create any dangerous oscillations when the student pilots apply abrupt, aggressive longitudinal inputs during high gain tasks such as gun tracking and close formation flight. Also, any attitude changes caused by the external disturbances such as gust or turbulence would not cause any divergent oscillations leading to overstress of the aircraft or PIO when the pilot attempts to return to the trim attitude.

Considering the role of the aircraft, especially initial phase of BFM setups, where the student pilot would fly keeping tally with adversary aircraft, if phugoid mode is excited due to gust, turbulence, pilot input or any other reason, oscillations would not create any dangerous characteristics or increase the student pilot's workload as the phugoid mode is convergent and sufficiently damped. Student pilot would be able to stop the phugoid and return to the trimmed conditions easily. Student pilot would also have enough time to react and stop the phugoid mode easily as the frequency of the mode was low.

L39's heavily damped (deadbeat) short period mode characteristics and long period mode with mild and long enough period of free response was evaluated as SATISFACTORY.

L39 was assessed Level 1 according to paragraph 3.2.2.1 of MIL-F-8785C [5] as the aircraft demonstrated high damping ratio by means of SPO.

L39 was assessed Level 1 according to paragraph 3.2.1.2 of MIL-F-8785C [5] as the aircraft demonstrated damping ratio over the minimum limit of 0.04 by means of phugoid mode.

2.4.3 Lateral / Directional Static Stability

LDSS tests, TP 3.12 through 3.15, were flown in first sortie by implementing test techniques as per ITPS LDSS Manual [15] for assessment. Test conditions were given below in Table 18.

TP#	Test Description	V_T (KIAS)	Altitude (ft)	Thrust (RPM)	A/C Weight (lb)
3.12, 3.14	WLSS / SHSS140 KIAS	140	8160	88.4%	9581
3.13, 3.15	WLSS / SHSS 200 KIAS	200	7400	88.7%	9219

Table 18: Test Conditions of LDSS

During the tests, maximum rudder input was applied as 100% as trimmed conditions were below V_A which was 230 KIAS derived from ITTC BFM SOP [23].

SHSS and WLSS test methods were combined. Once the aircraft was trimmed in test conditions, pilot applied pre-determined pedal input and kept the heading steady with aileron inputs to the opposite side. After aircraft was stabilized in a steady sideslip condition, pilot initially released the lateral controls to observe the raise of the low wing, then the rudder controls to observe recovery from sideslip. Tests were repeated for two different rudder deflection in both directions. Pedal forces were qualitatively assessed, and sideslip data was taken with the heading difference between the moment that pedals were released and the moment that the aircraft was fully recovered from sideslip. Handwritten gathered data was presented in Annex F.2, Table 41. Data reduction was introduced in Annex F.3.6.

L39 showed positive lateral and directional static stability as the aircraft raised the low wing when aileron force eased, and nose direction changed towards sideslip (opposite of rudder deflection side) when rudder force released during both in 140 and 200 KIAS test points.

Second order polynomial was fitted to rudder / aileron force and bank angle versus sideslip and was depicted in Figure 27 for 140 KIAS.

Description	WLSS / SHSS 140 KIAS	Test Point #	3.12, 3.14
Aircraft	L39	A/C Registration	CGFNO
Date	22 NOV 2022	OAT	0 °C
Altitude	8000 ft	CG	22.8%
Weight	9581 lb	Config.	Clean / Cruise
Thrust	88.4% RPM		

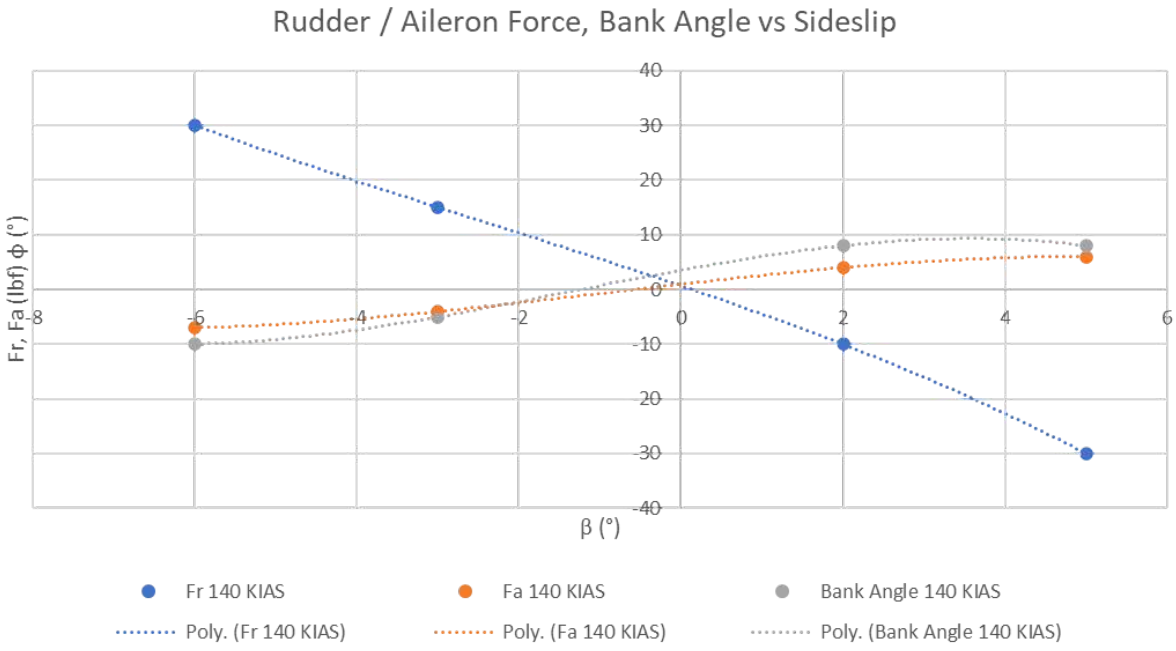


Figure 27: Test Results of LDSS for 140 KIAS

There was no objection by means of linearly increasing force and deflection of rudder and aileron with sideslip during 140 KIAS TP. No reversal or lightening was encountered, and aircraft did not cause any uncontrollable flight characteristics when the lateral controls were released in a steady sideslip. Only, during 140 KIAS %100 right rudder deflection SHSS, test pilot felt light buffet that didn't cause to terminate TP.

Second order polynomial was fitted to rudder / aileron force and bank angle versus sideslip and was depicted in Figure 28 for 200 KIAS.

Description	WLSS / SHSS 200 KIAS	Test Point #	3.13, 3.15
Aircraft	L39	A/C Registration	CGFNO
Date	22 NOV 2022	OAT	0 °C
Altitude	8000 ft	CG	22.6%
Weight	9219 lb	Config.	Clean / Cruise
Thrust	88.7% RPM		

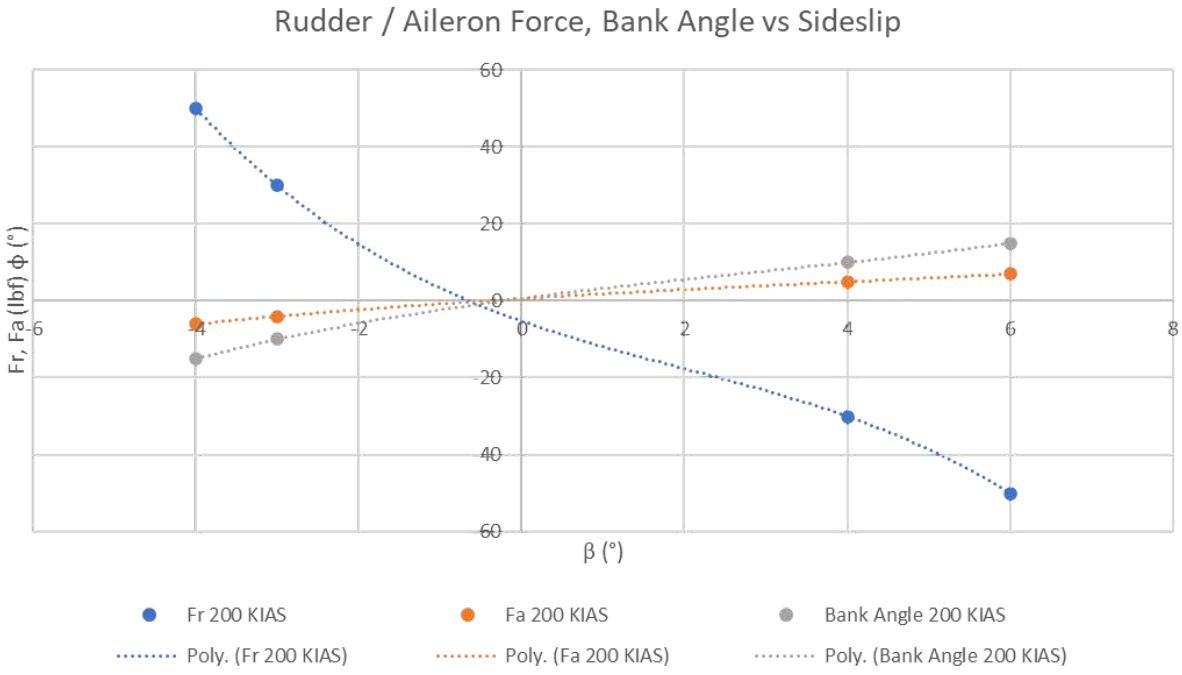


Figure 28: Test Results of LDSS for 200 KIAS

There was also no objection by means of linearly increasing force and deflection of rudder and aileron with sideslip during 200 KIAS TP. No reversal or lightening was encountered, and aircraft did not cause any uncontrollable flight characteristics when the lateral controls were released in a steady sideslip for tested conditions.

During 140 KIAS and 200 KIAS SHSS with left and right 100% rudder deflection, stick force was applied to pull 4 lbf and 5 lbf respectively in order to keep airspeed constant which were found to be inside limits of 10 lbf pull and 3 lbf push in MIL-F-8785C [5].

Considering the role of the aircraft, positive lateral and directional stability of L39 would help student pilots handling during BFM tasks. Increasing rudder and aileron forces would hinder student pilots go beyond structural limits of the aircraft among the maneuvers. Besides aircraft's capability to follow a steady track with SHSS would allow student pilots to observe adversary's first maneuver to select one or two circle fight if it was coming below student pilot's aircraft. Student pilots could determine the direction of fight according to adversary's thrust limited, turn limited or similar bandit simulations. Student pilots would give the chance of lead turn advantage to opposing aircraft, trading off one / two circle fight selection. In those cases, pilots should do a typical steady heading side slip while maintaining their altitude and track. A satisfactory lateral /

directional static stability would encourage pilot to do this plan. After seeing bandit's turn direction, student pilot would have the chance to win the fight as he/she could use the advantage of bandit's deficiencies of limited thrust or turn.

L39's lateral-directional static stability with increasing rudder and aileron force due to sideslip angle and tendency to recover from wings level and steady heading sideslip conditions were assessed as SATISFACTORY.

Further testing should be performed with an onboard FTI capable of measuring control forces and displacements as well as the sideslip angles for further analysis before procurement (DESIRABLE - EFFECTIVENESS).

L39 was assessed Level 1 for MIL-F-8785C [5] 3.2.3.7 longitudinal control in sideslips requirements in that, the airplane trimmed for straight, level flight with zero sideslip, the pitch-control force required to maintain constant speed in steady sideslips with up to 50 pounds of pedal force in either direction did not exceed the pitch-control force that would result in a 1 g change in normal acceleration. pitch-control force did not exceed 10 pounds pull to 3 pounds push.

L39 was assessed Level 1 for MIL-F-8785C [5] 3.3.6.1 requirements in that, right yaw-control pedal deflection and force produced left sideslips and left yaw-control-pedal deflection and forces produced right sideslips. The variation of sideslip angle with yaw-control-pedal deflection was essentially linear for sideslip angles between +15 degrees and - 15 degrees.

L39 was assessed Level 1 for MIL-F-8785C [5] 3.3.6.2 and 3.3.6.3 requirements in that, the increase in right bank angle, right lateral control displacement and right lateral force accompanied an increase in right sideslip with linear variation and vice versa.

L39 was assessed Level 1 for MIL-F-8785C [5] 3.3.6.3.2 requirements in that, positive effective dihedral (right roll control for right sideslip and left roll control for left sideslip) was below 75% of roll control power available, and 10 pounds of roll-stick force.

L39 was assessed Level 1 for MIL-F-8785C 3.3.5 [5] requirements in that, directional stability and control characteristics enabled the pilot to balance yawing moments and control yaw and sideslip. Sensitivity to yaw control pedal forces were sufficiently high that directional control and force requirements could be met, and satisfactory coordination could be achieved without unduly high pedal forces.

2.4.5 Lateral / Directional Dynamic Stability

LDDS tests, TP 3.16 and 3.17, were flown in first sortie by implementing test techniques as per ITPS LDDS Manual [16] for assessment. Test conditions were given below in Table 19.

TP#	Test Description	V_T (KIAS)	Altitude (ft)	Thrust (RPM)	A/C Weight (lb)
3.16	Dutch Roll 140 KIAS	140	8060	88.4%	9519
3.17	Dutch Roll 200 KIAS	200	7080	88.6%	9139

Table 19: Test Conditions of LDDS

Dutch roll tests were performed at dedicated airspeeds with either rudder fixed and free using doublet FTT. Aircraft's V_A was determined from ITTC BFM SOP [23] to be 230 KIAS, even though, test points were conducted with %50 rudder maximum deflection below V_A for risk mitigation. Time to zero amplitude, overshoots, maximum bank angle, maximum sideslip were recorded by hand, yaw rate and roll rate in time were recorded by iLevel presented in Annex F.2, Table 42.

With the collected data, damping ratio, natural and damped frequencies, periods, time to half amplitudes and cycles to 1/10 amplitude were calculated by modelling the test data using the general 2nd order dynamic system free response equation given in Annex F.3.7. Test results were shown in Table 20.

TP#	V_i (KIAS)	Controls	ζ	ω_n (rad/s)	ω_d (rad/s)	T (sec)	$T_{1/2}$ (sec)	$\xi^*\omega_n$
3.16	140	Fixed	0.145	2.646	2.618	2.4	1.8	0.384
3.16	140	Free	0.145	2.268	2.244	2.8	2.1	0.354
3.17	200	Fixed	0.091	4.071	4.054	1.6	1.9	0.371
3.17	200	Free	0.081	4.391	4.377	1.4	1.9	0.356

Table 20: Test Results of Dutch Roll

It was assessed that there was negligible difference between the controls fixed and controls free response where the controls free oscillation resulted slightly lower damping ratio generally. Low damping ratio and high natural frequency were observed. Minimum limits of damping, frequency and damping*frequency were depicted in Figure 29 according to paragraph 3.3.1.1 of MIL-F-8785C [5].

TABLE VI. Minimum Dutch roll frequency and damping.

Level	Flight Phase Category	Class	Min ζ_d*	Min $\zeta_d\omega_{nd}$* rad/sec.	Min ω_{nd} rad/sec.
1	A (CO and GA)	IV	0.4	-	1.0
	A	I, IV	0.19	0.35	1.0
		II, III	0.19	0.35	0.4**
	B	All	0.08	0.15	0.4**
	C	I, II-C, IV	0.08	0.15	1.0
		II-L, III	0.08	0.10	0.4**
2	All	All	0.02	0.05	0.4**
3	All	All	0	0	0.4**

Figure 29: Minimum Parameters of Dutch Roll (MIL-F-8785C)

L39 demonstrated damping qualities below air-to-air combat phase (CO) and Level 1 Category A Class IV aircraft limits (yellow column in Table 20).

Dutch roll oscillations at tested conditions did not cause any uncontrollable or dangerous flight characteristics, leaned to converge, but increased pilot workload and caused discomfort. Dutch roll yaw and roll rate against time graphics were illustrated in Figure 30 and Figure 31.

Description	Dutch Roll 140 KIAS	Test Point #	3.16
Aircraft	L39	A/C Registration	CGFNO
Date	22 NOV 2022	OAT	0 °C
Altitude	8000 ft	CG	22.7%
Weight	9519 lb	Config.	Clean / Cruise
Thrust	88.4% RPM		

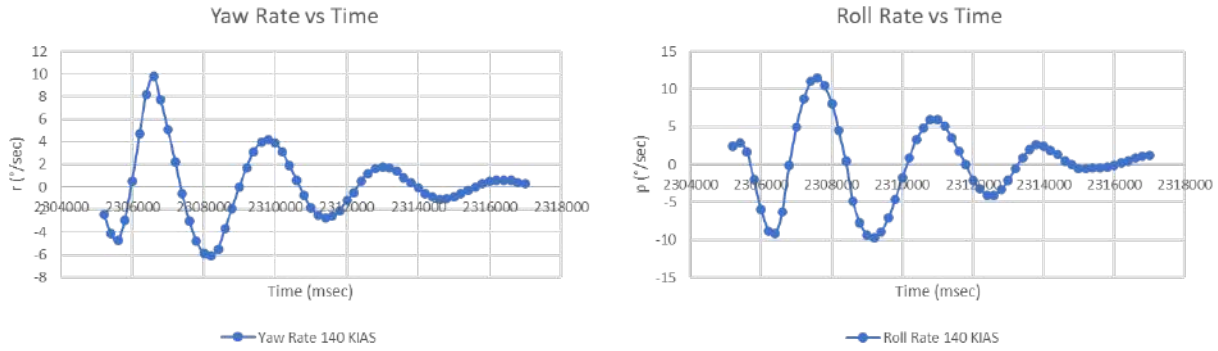


Figure 30: Dutch Roll Graphical Results for 140 KIAS

Description	Dutch Roll 200 KIAS	Test Point #	3.17
Aircraft	L39	A/C Registration	CGFNO
Date	22 NOV 2022	OAT	0 °C
Altitude	7000 ft	CG	22.5%
Weight	9139 lb	Config.	Clean / Cruise
Thrust	88.6% RPM		

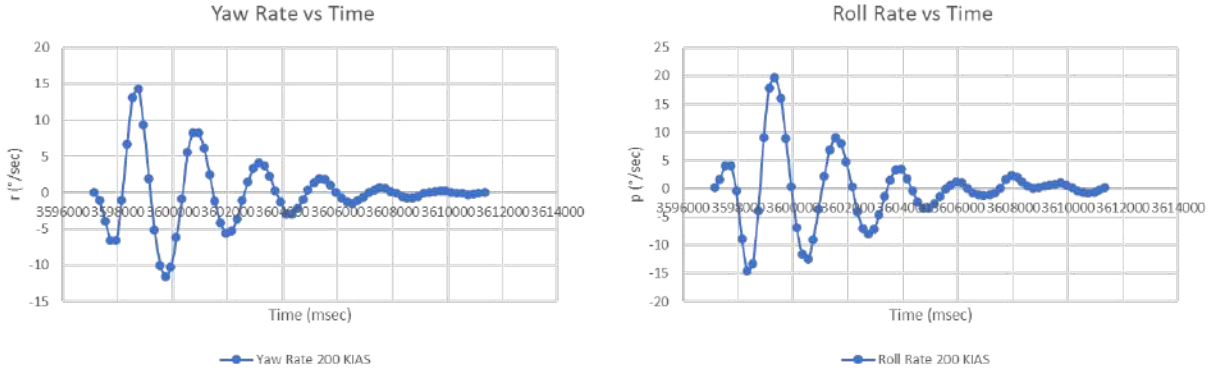


Figure 31: Dutch Roll Graphical Results for 200 KIAS

Any disturbance such as gust or pilot input that creates a sufficient sideslip change will excite the Dutch roll mode. L39 during BFM tasks could be impacted due to low damping ratio of Dutch roll especially at the initial phase of the setups. Student pilots should establish stable conditions before fights on and during setup start up, overwhelmingly they should look outside in order not to lose sight of adversary aircraft. Trigger of Dutch roll would disorient student pilot because of diversion of focus to trials to stable the aircraft which could lead late starts of setup that would cause more fuel consumption and less setups in consequence. During the high gain tasks like gun tracking or close formation flight, triggered Dutch roll could hinder valid gun shots or could lead oscillations which would result to get away from lead aircraft to settle for safety. During formation approach to landing pattern, distracted aircraft could separate from formation flight that could cause to maintain route formation.

Low damped Dutch roll mode of L39 below air-to-air phase and Level 1 Category A Class IV minimum limit of MIL-F-8785C [5] was assessed as UNSATISFACTORY (CLASS III).

Procuring activity (COAF) should assess consequences and impacts of Level 2 Dutch role mode before agreement (DESIRABLE - EFFECTIVENESS).

L39's Dutch roll characteristics met MIL-F-8785C [5] paragraph 3.3.1.1 as Level 2.

2.4.6 Roll Performance

Roll performance tests, TP 3.18 and 3.19, were flown in first sortie by implementing test techniques as per ITPS LDDS Rolling Performance Manual [17] for assessment. Test conditions were given below in Table 21.

TP#	Test Description	V_T (KIAS)	Altitude (ft)	Thrust (RPM)	A/C Weight (lb)
3.18	Roll Performance 140 KIAS	140	7840	88.3%	9466
3.19	Roll Performance 200 KIAS	200	7200	88.6%	9077

Table 21: Test Conditions of Roll Performance

Roll performance was tested bank to bank between 45° banks. During the maneuver, test pilot didn't apply rudder. First 50% aileron deflection was tested for build up approach, then 100% aileron deflection was implemented for data. Data was collected either with hand by means of time hack and with iLevel by means of roll rate as introduced in Annex F.2, Table 43. Test pilot also gave aileron roll forces to be noted. With the help of iLevel, roll rate versus time information was used to get roll mode time constant after data reduction (Annex F.3.8) for 140 and 200 KIAS left to right 45° bank to bank 100% aileron input roll as depicted in Figure 32 and Figure 33.

Description	Roll Mode 140 KIAS	Test Point #	3.18
Aircraft	L39	A/C Registration	CGFNO
Date	22 NOV 2022	OAT	0 °C
Altitude	8000 ft	CG	22.6%
Weight	9466 lb	Config.	Clean / Cruise
Thrust	88.3% RPM		

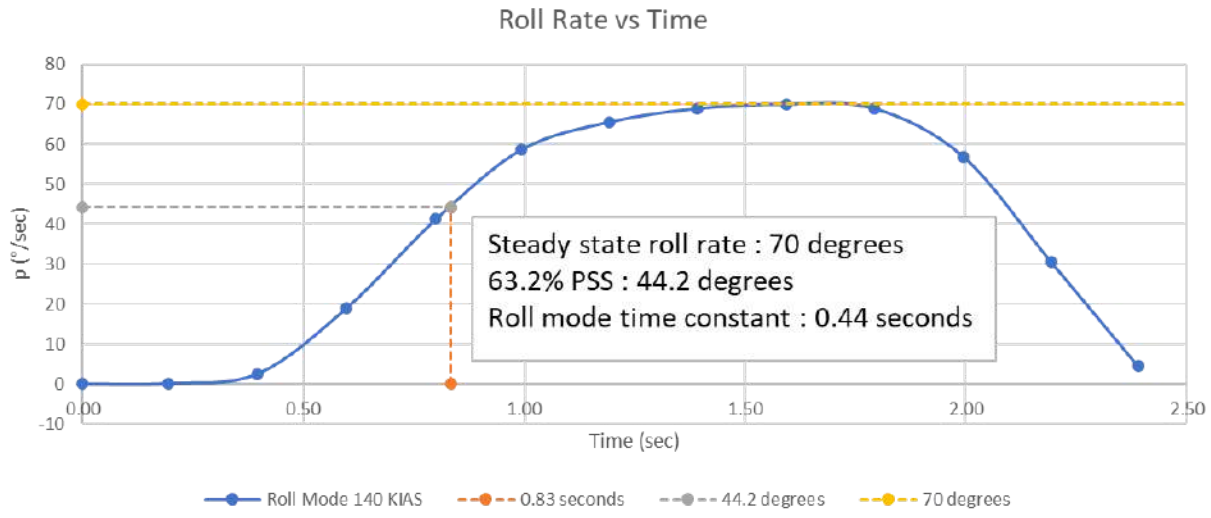


Figure 32: Roll Mode Time Constant for 140 KIAS

Description	Roll Mode 200 KIAS	Test Point #	3.19
Aircraft	L39	A/C Registration	CGFNO
Date	22 NOV 2022	OAT	1 °C
Altitude	7200 ft	CG	22.5%
Weight	9077 lb	Config.	Clean / Cruise
Thrust	88.6% RPM		

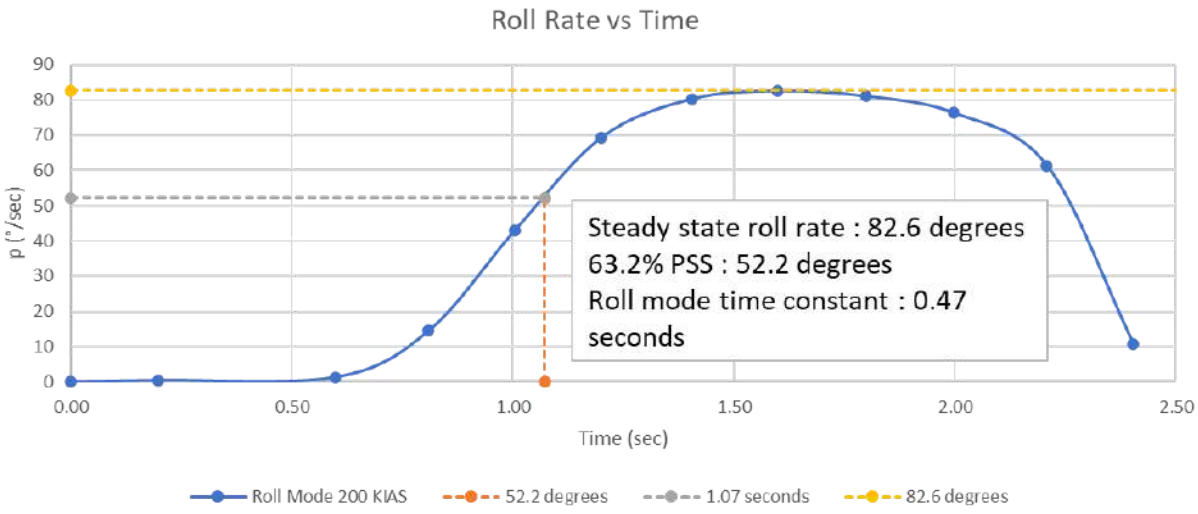


Figure 33: Roll Mode Time Constant for 200 KIAS

L39 demonstrated a sufficient lateral control power and roll rate with a controllable attitude. There was no tendency for sustained or uncontrollable lateral-directional oscillations resulting from efforts of the test pilot to control the airplane.Test results were given in Table 22 in terms of the time taken to roll through a 90° bank angle change with full aileron step input, compared to the MIL-F-8785C paragraphs 3.3.1.2 and 3.3.4.1 for minimum time requirements.

TP#	V_i (KIAS)	Roll Direction	Time to Roll 90° Test (sec)	Time to Roll 90° MIL-F-8785C (sec)	Time Constant Test (sec)	Time Constant MIL-F-8785C (sec)
3.18	140	L to R	1.3	1.3	0.44	1.0
3.18	140	R to L	1.29		-	
3.19	200	L to R	1.28		0.47	
3.19	200	R to L	1.12		-	

Table 22: Test Results of Roll Performance

Time to roll 90° and time constant values were found to be lower than MIL-F-8785C requirements. Roll control aileron forces were also found to be 4 lbf for 50% aileron input and 10 lbf for 100% aileron input to both sides as given in Annex F.2, Table 43. There were no objectionable nonlinearities in the variation of rolling response with roll control deflection or force. L39 demonstrated a roll response to roll control force not greater than 15 degrees in 1

second per pound (MIL-F-8785C Level 1 limit) as illustrated in Figure 34 after data reduction (Annex F.3.9).

Description	Roll Mode 140, 200 KIAS	Test Point #	3.18, 3.19
Aircraft	L39	A/C Registration	CGFNO
Date	22 NOV 2022	OAT	0, 1 °C
Altitude	8000, 7200 ft	CG	22.6, 22.5%
Weight	9466, 9077 lb	Config.	Clean / Cruise
Thrust	88.3, 88.6% RPM		

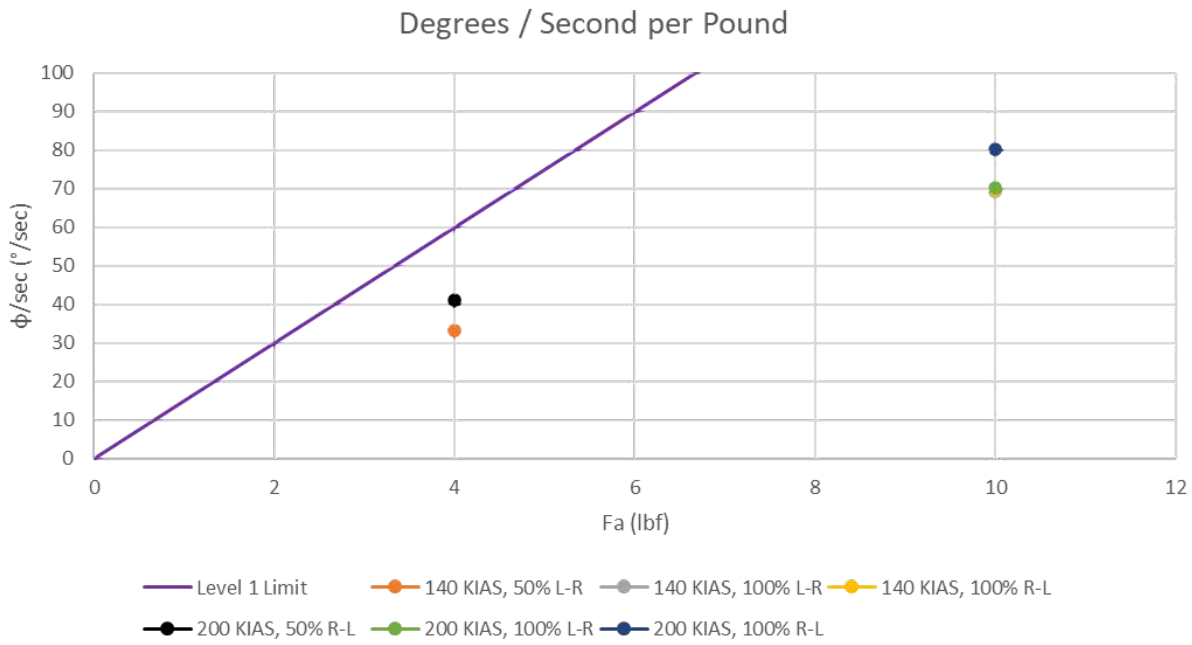


Figure 34: Roll Response for 140 KIAS / 200 KIAS

Roll performance of L39 couldn't be investigated with 360° roll and roll under load factor due to concerns of time limit presented in paragraph 1.6. Turn coordination, roll induced oscillations, and side slip excursions couldn't be tested because of time limit of test campaign and lack of onboard FTI.

BFM missions would highly require roll performance as it would be the one of basic BFM mechanics, roll, turn and accelerate. To be able attack on adversary, student pilots should be in range, in plane and in lead according to adversary. L39 would satisfy student pilots to roll aircraft with agile inputs and reactions to be in plane with bandit or get away from bandit's plane of motion to deny WEZ. Student pilots could generate yo-yos or 360 rolls easily to adjust distance with opposing aircraft. They could also be able to put efficient lift vector onto offensive bandit to deny WEZ by using roll capability. Roll would be another key factor to establish tally and maintain it as L39 would stimulate COAF student pilots' tally on adversary in order not to lose sight and lose fight.

L39's roll performance with sufficient lateral control power, roll rate and roll response was assessed as SATISFACTORY.

Further tests should be done to satisfy procurement agency to comply with paragraphs 3.3.2.2, 3.3.2.3, 3.3.2.4, 3.3.2.5, 3.3.2.6 and 3.3.4.1.1 of MIL-F-8785C [5] (DESIRABLE - EFFECTIVENESS).

Further tests should be reiterated with onboard FTI to get exact aileron forces (DESIRABLE - EFFECTIVENESS).

L39's roll rate, roll response, aileron force and flying qualities met requirements of Level 1 for paragraphs 3.3.1.2, 3.3.3, 3.3.4.1, 3.3.4.1.3 and 3.3.4.3 of MIL-8785C [5].

2.4.7 Longitudinal Maneuver Stability

LMS tests, TP 3.10 and 3.11, were flown in second sortie by implementing test techniques as per ITPS LMS Manual [13] for assessment. Test conditions were given below in Table 23.

TP#	Test Description	V_T (KIAS)	Altitude (ft)	Thrust (RPM)	A/C Weight (lb)
3.10	Stabilized Turn 140 KIAS	140	9100	88.4%	8576
3.11	Stabilized Turn 200 KIAS	201	8020	88.6%	8718

Table 23: Test Conditions of LMS

Test points 3.11 and 3.12 were performed at two different target airspeed conditions (140 KIAS and 200 KIAS). Aircraft was trimmed at required airspeed, altitude and thrust condition in clean / cruise configuration. Then, test pilot started to apply smooth bank angle with increasing normal acceleration while keeping the airspeed constant. When stabilized, the stick force was given by pilot qualitatively. Test was performed for preplanned G points until buffets were observed for only left side due to limited flight hour. Airspeed, load factor, angle of bank, altitude, engine RPM, stick force and fuel parameters were recorded by hand. Gathered test data was introduced in Annex F.2, Table 44 and Table 45.

It was assessed that there was no non-linearity and alleviation in the gradient of the curve of stick force versus normal load factor with increasing load factor for all test points. There was no tendency for the aircraft attitude to diverge aperiodically with the constant elevator input. Incremental control force and displacement was required to maintain a change in normal load factor. Test results were given in Table 24 in terms of stick force curve slope (F_e/n_z). Data reduction was introduced in Annex F.3.10.

TP #	Test Description	V_i (KIAS)	F_e/n_z (lbf/G)
3.10	Stabilized Turn 140 KIAS	120	4.5
3.11	Stabilized Turn 200 KIAS	120	8.4

Table 24: Test Results of LMS

MIL-F-8785C maximum gradient limit was related to aircraft's n_z/α parameter. Since the α could not be measured due to lack of instrumentation, n_z/α was not assessed. However, MIL-F-8785C also specified that the maximum force gradient for Level 1 could not be greater than $\frac{56}{n_L-1}$, resulting a 8.6 lbf/G for L39 and minimum force gradient for Level 1 could not be less than $\frac{21}{n_L-1}$, resulting a 3.2 lbf/G for L39. Comparison of the test results with the MIL-F-8785C [5] paragraph 3.2.2.2.1 was given in Table 25, and shown in Figure 35.

Maximum Force Gradient $F_e/n_{z\text{max}}$ (lbf/G)	Test 200 KIAS F_e/n_z (lbf/G)	Test 140 KIAS F_e/n_z (lbf/G)	Minimum Force Gradient $F_e/n_{z\text{min}}$ (lbf/G)
8.6	8.4	4.5	3.2

Table 25: Max. / Min. Force Gradient Comparison of MIL-F-8785C

Description	LMS 140 / 200 KIAS	Test Point #	3.10, 3.11
Aircraft	L39	A/C Registration	CGFNO
Date	23 NOV 2022	OAT	0 °C
Altitude	8000 ft	CG	23.5%
Weight	8576-8718 lb	Config.	Clean / Cruise
Thrust	88.4-88.6% RPM		

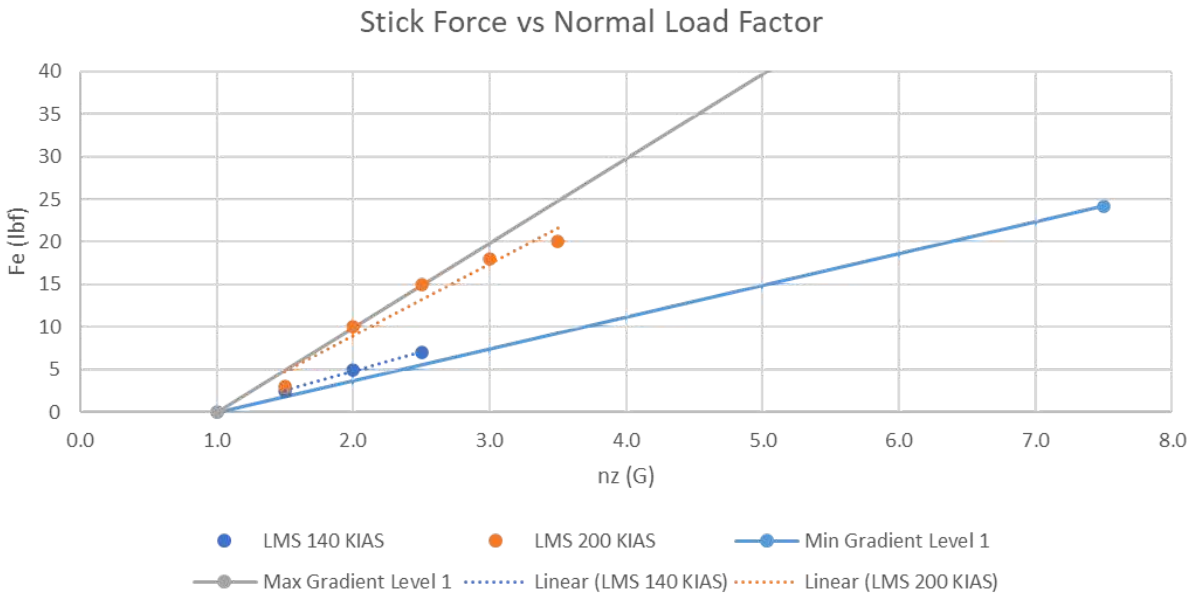


Figure 35: Stick Force vs Normal Load Factor with MIL-F-8785C Comparison

Longitudinal control in unaccelerated flight (paragraph 3.2.3.1), longitudinal control in maneuvering flight (paragraph 3.2.3.2) and control motions in maneuvering flight (paragraph 3.2.2.2.2) of MIL-F-8785C [5] couldn't be tested due to time constraint and lack of onboard FTI as discussed in paragraph 1.6.

Positive longitudinal maneuvering stability of L39 would assist student pilots during BFM setups as linearity between force and load factor assures coordinated inputs to controls and reactions from the aircraft. The sufficient magnitude of the stick force gradient would prevent the student pilot from inadvertently overstressing the aircraft during maneuvering flight. On the other hand, the low enough stick force gradient would also allow the student pilot to maneuver the aircraft without causing excessive forces and fatigue.

L39's longitudinal maneuvering stability with linear and sufficient stick force gradients was assessed as SATISFACTORY.

Further testing should be reiterated with an onboard FTI capable of measuring control forces and displacements for further analysis before procurement (DESIRABLE - EFFECTIVENESS).

Further testing should be performed with an onboard FTI capable of measuring control forces and displacements for paragraph 3.2.3.1 longitudinal control in unaccelerated flight, paragraph

3.2.3.2 longitudinal control in maneuvering flight and paragraph 3.2.2.2.2 control motions in maneuvering flight derived from MIL-F-8785C [5] (DESIRABLE - EFFECTIVENESS).

L39's control forces in maneuvering flight met the MIL-F-8785C 3.2.2.2.1 as Level 1 in that the stick force gradients were within the specified limits without non-linearities.

L39's control forces in maneuvering flight met the MIL-F-8785C 3.2.2.3.2 as Level 1 in that the deflection of the pilot's control did not lead the control force throughout the frequency range of pilot control inputs and the peak pitch control forces developed during abrupt maneuvers was not objectionably light, and the buildup of control force during the maneuver entry led the buildup of normal acceleration.

2.5 Formation Flight HQ and Workload Evaluation

Formation flight HQ and workload tests, through TP 4.1 to TP 4.4 and TP 5.1, were flown in third and fourth sorties by implementing test techniques as per ITPS Flying Qualities Manual – Chapter 15, "Handling Qualities" [19] and ITPS Workload Lecture Notes "GENAVIOCH19 - Cockpit Workload" [22]. Cooper Harper rating scale (Annex E.7) and PIO rating scale (Annex E.8) were used for handling quality assessment, Bedford workload rating scale (Annex E.9) was used to assess workload during the tests. Data was collected via handwriting. Test conditions were given below in Table 26.

TP#	Test Description	V_T (KIAS)	Altitude (ft)	Thrust (RPM)	A/C Weight (lb)
4.1 / 5.1	Steady Fingertip	190	7500	TFLF	9841 to 9487
4.2 / 5.1	Maneuvering Fingertip	190	7500	TFLF	
4.3	Capture Fingertip	190	7500	TFLF	
4.4	Capture Line Astern	190	7500	TFLF	

Table 26: Test Conditions of Formation Flight

Steady fingertip HQ (TP 4.1) and workload (TP 5.1) were evaluated for both sides, left hand side and right-hand side formation flight.

Objective was to maintain echelon position of test aircraft in all axes throughout the evaluation. Performance was measured for maximum deviation of:

- Desirable: 1 ft,
- Adequate: 2 ft.

Additional tasks for one time execution were created to represent real circumstances as:

1. Radio frequency change (passive to active selection),
2. Adapt to new radio station level of volume,
3. Engine parameters check (green).

Test results were presented in Table 27.

Task	Performance	CHRS	PIO RS	WL RS
Right hand side echelon (main task)	Desired	1	1	1
Radio freq. change (additional)	Adequate	-	2	5
Volume adjustment (additional)	Adequate	-	2	5
Engine parameters check (additional)	Desired	-	1	3
Left hand side echelon (main task)	Desired	1	1	1
Radio freq. change (additional)	Adequate	-	2	6
Volume adjustment (additional)	Adequate	-	2	6
Engine parameters check (additional)	Desired	-	1	3

Table 27: Test Results of TP 4.1 / 5.1

For right and left steady echelon flight, handling qualities were rated of 1 (CHRS) as test pilot compensation was not a factor for desired performance (excellent, highly desirable). CHRS wasn't applied with additional tasks as performance decrease was observed, not because of HQ characteristics of aircraft, but because of workload increase.

PIO tendency wasn't encountered during steady echelon at both sides and during engine parameters visual check (rated 1). When formation flight was subject to additional tasks using test pilot's hand for physical change, pilot had to move his head out of lead a/c for a while to enter / change parameters by hand, thus, created minor deficiencies with the position of a/c. When pilot looked again to lead, he had to modify his position after that disturbance, so, undesirable motions tended to occur when pilot initiated abrupt maneuvers or attempted tight control. These motions could be prevented or eliminated by pilot technique (rated 2).

Workload was significantly increased as pilot had difficulty during frequency change and volume adjustment even though he only put pre-set frequency to active state. It was assessed that frequency typing would have resulted to abandon formation flight, but it was unlikely to type frequency while keeping close formation position. Due to position of the PFD, pilot had slight difficulty on the left side as lead a/c exceeded peripheral limit of the test pilot's FOV, thus, left hand side workload ratings became higher than right hand side.

Maneuvering fingertip HQ and workload was evaluated for both sides, left hand and right hand with either turns towards or away from test a/c.

Objective was to maintain echelon position of test aircraft in all axes throughout the evaluation. Performance was measured for maximum deviation of:

- Desirable: 2 ft,
- Adequate: 3 ft.

Additional task for one time execution were created to represent real circumstances as:

1. Engine parameters check (green).

Lead aircraft did bank angle changes from level flight to 30° (bank angle change of 30°), from 30° bank to level flight (bank angle change of 30°) or from 30° bank to 30° bank to other direction (bank angle change of 60°).

Maneuvering fingertip test point didn't give different results according to left hand or right-hand side echelon positions, so, presentation was made as below in Table 28.

Task	Performance	CHRS	PIO RS	WL RS
Away from 30° bank (main task)	Desired	1	1	2
Away from 30° bank, engine parameters check (additional)	Desired	-	1	3
Towards 30° bank (main task)	Desired	1	1	2
Towards 30° bank, engine parameters check (additional)	Adequate	-	2	4
Bank angle change of 30°	Desired	2	2	-
Bank angle change of 60°	Desired	3	2	-

Table 28: Test Results of TP 4.2 / 5.1

Steady state banks were evaluated as 1 by means of CHRS as test pilot compensation was not a factor for desired performance (excellent, highly desirable). 30° bank angle change did not require pilot compensation for desired performance (good, negligible deficiencies). 60° bank angle change required minimal pilot compensation (fair, some mildly unpleasant deficiencies) as it was rated 3 of CHRS because of the relatively bigger bank angle change. CHRS wasn't applied with additional task as performance decrease was observed, not because of HQ characteristics of aircraft, but because of workload increase.

PIO was increased slightly during 30° steady bank towards test a/c with additional task as test pilot had to move his head out of lead a/c, thus, created minor deficiencies with the position of a/c. When pilot looked again to lead, he had to modify his position after that disturbance, so, undesirable motions tended to occur when pilot initiated abrupt maneuvers or attempted tight control. It was also applicable to rate PIO as 2 with bank angle changes (both 30° and 60°) as a/c had dynamic disturbances to be modified. These motions could be prevented or eliminated by pilot technique.

Workload was increased slightly and overshot to a/c's out of desired limits with additional task during 30° bank towards test a/c as it was more challenging than 30° bank away from test a/c as shown in 5th column of Table 28.

Capture fingertip handling quality tests were evaluated for both sides, left hand and right hand. Objective was to capture fingertip position from 10 ft below. Performance was measured for duration of:

- Desirable: 3 sec,
- Adequate: 5 sec.

Workload wasn't applied as TP required dynamic maneuver for a short time. Test results were introduced in Table 29.

Task	Performance	CHRS	PIO RS
Right hand side	Desired	3	2
Left hand side	Desired	3	2

Table 29: Test Results of TP 4.3

Performance was at limits of 3 seconds; CHRS was graded as 3 and required minimal pilot compensation (fair, some mildly unpleasant deficiencies) for desired performance. As it was a dynamic TP by means of PIO, undesirable motions tended to occur when pilot initiated abrupt maneuvers or attempted tight control. These motions could be prevented or eliminated by pilot technique (rated 2).

Capture line astern handling quality tests were evaluated for both sides, left to right hand (to line astern) and right to left hand (to line astern). Objective was to capture line astern position from 10 ft lateral offset from line astern position. Performance was measured for duration of:

- Desirable: 3 sec,
- Adequate: 5 sec.

Workload wasn't applied as TP required dynamic maneuver for a short time. Test results were shown as Table 30.

Task	Performance	CHRS	PIO RS
From right to line astern	Desired	2	2
From left to line astern	Desired	2	2

Table 30: Test Results of TP 4.4

Performance was 2 seconds; CHRS was graded as 2 and did not require pilot compensation (good, negligible deficiencies) for desired performance. As it was a dynamic TP by means of PIO, undesirable motions tended to occur when pilot initiated abrupt maneuvers or attempted tight control. These motions could be prevented or eliminated by pilot technique (rated 2).

L39 would introduce a sufficient handling characteristic to student pilots of COAF while flying close formation at steady states or small dynamic circumstances. If large amplitude of dynamic motion was encountered during close formation phase, they would have to adapt themselves to counter those circumstances. They would also subject to some minor PIO occurrences but could prevent them easily with aircraft's sufficient handling quality characteristics.

Avionics coating to L39 would give student pilots some comfort but some difficulties in addition due to touch screen feature of it. While flying formation, there would be requirements to change radio frequency or adjust radio volume or update given QNH value and so on. Those kind of inputs to aircraft with hand, especially using touch feature of screens could impact formation flight quality by means of not able to maintain the exact position. Position deviation away from lead a/c would not impact safety but deviations towards lead a/c could lead to mid air collision probabilities. If the student pilot would be expected to enter a new radio frequency, he / she might abandon formation flight to extend distance away from lead a/c to be on the safe side, even though this need would be unlikely. Those concerns would not affect mission effectiveness during VMC flights. Considering transition to 5th generation aircrafts which were coated with hands on throttle solutions, multiple pre-set radio frequency capabilities, L39 would be insufficient to simulate those kinds of features. This would lead student pilots to evolve themselves to a very different and sophisticated aircraft system when they attended to 5th generation training.

L39's avionics coating contribution to formation flight was assessed UNSATISFACTORY (CLASS III).

HOTAS capability should be coated to L39 (DESIRABLE-EFFECTIVENESS) to be able transmit from both radios.

Pre-set frequency capability should be brought to L39's avionics system (DESIRABLE-EFFECTIVENESS).

Any physical inputs to aircraft's avionics system should be emphasized by extending distance from lead aircraft during close formation in SOP of COAF (DESIRABLE-EFFECTIVENESS).

2.6 BFM Mission HQ and Workload Evaluation

BFM mission HQ and workload tests, TP 4.5, TP 4.6, and TP 5.2, were flown in third and fourth sorties by implementing test techniques as per ITPS Flying Qualities Manual – Chapter 15, "Handling Qualities" [19] and ITPS Workload Lecture Notes "GENAVIOCH19 - Cockpit Workload" [22]. Cooper Harper rating scale (Annex E.7) and PIO rating scale (Annex E.8) were used for handling quality assessment, Bedford workload rating scale (Annex E.9) was used to assess workload during the tests. Data was collected via handwriting. Test conditions were given below in Table 31.

TP#	Test Description	V_T (KIAS)	Altitude (ft)	Thrust (RPM)	A/C Weight (lb)
4.5 / 5.2	Offensive BFM	200	7500	103%	9399 to 8868
4.6 / 5.2	Defensive BFM	140	7500	MAX	

Table 31: Test Conditions of BFM Mission

BFM setups were performed with recommended display set determined on ground as discussed in paragraph 2.1.3.

Offensive BFM setup was evaluated for HQ and workload with additional tasks. Main task was gun tracking over adversary with minimum duration of:

- Desirable: 3 sec,
- Adequate: 2 sec.

Additional tasks were to:

1. Presume bandit's range via visual cues (reticle),
2. Pursue KIO criteria (floor and 1.1Vs),
3. Maintain %103 RPM due to altitude change,
4. Pursue joker fuel.

Objectives during additional tasks were:

1. Bandit's range estimation:
    - Desirable: +/- 500 ft,
    - Adequate: +/- 1000 ft.
2. Pursuing KIO criteria:
    - Desirable: floor and 1.1Vs,
    - Adequate: one of them (floor or 1.1Vs).
3. Maintaining 103% RPM:
    - Desirable: +0 / -3 RPM,
    - Adequate: +0 / -5 RPM.
4. Pursuing joker fuel:
    - Desirable: two times,
    - Adequate: one time.

Test results were presented in Table 32.

Task	Performance	CHRS	PIO RS	WL RS
Gun track (main task)	Desired	2	1	-
Estimate bandit's range (additional)	Adequate	-	1	4
Pursue KIO criteria (additional)	Desired	-	1	2
Maintain 103% RPM (additional)	Desired	-	1	3
Pursue joker fuel (additional)	Desired	-	1	3

Table 32: Test Results of TP 4.5 / 5.2

During offensive BFM setup, adversary aircraft maintained 180-200 KIAS, 2 G, conducted a flat turn towards test a/c simulating rate fight and positioned itself to give appropriate conditions for test aircraft to execute gun exercise. Test pilot could easily position L39 to WEZ and shoot over bandit's empennage lasting 5 to 8 seconds. Performance was inside desired limits. No PIO tendency was observed.

Workload evaluation was performed during offensive BFM task outside the gun tracking conditions. Range estimation created higher workload and gave adequate performance comparing to other additional tasks which was rated 4 according to Bedford WL RS. It was because of reticle gun sight radian cues to be applied to presume bandit's relative range.

Offensive BFM task was found to be easier than defensive as pilot was looking forward and could monitor pertinent parameters relatively in favour as primary instruments were presented inside the optimum FOV of test pilot. Aircraft handling quality was sufficient to maintain gun tracking over desired performance criteria.

The most prominent handicap of offensive BFM was about range estimation. Even though gun sight reticle gave some cues by means of radians to determine range of adversary, it was not so accurate. This deficiency created considerable workload over test pilot.

Defensive BFM setups (reiterated 3 times) were evaluated for HQ and workload with additional tasks. Main task was to acquire a position of advantage (denying WEZ) which was neutral or at least pulling according to adversary until close to floor as listed below:

- Desirable: neutral,
- Adequate: pulling.

Additional tasks were to:

1. Pursue KIO criteria (floor and 1.1Vs),
2. Pursue altitude for vertical maneuver,
3. Pursue joker fuel.

Objectives during additional tasks were to be:

1. Pursuing KIO criteria:
    - Desirable: both,
    - Adequate: one of them.
2. Pursuing altitude for vertical maneuver:
    - Desirable: two times,
    - Adequate: one time.
3. Pursuing joker fuel:
    - Desirable: two times,
    - Adequate: one time.

Test results were presented in Table 33.

Task	Performance	CHRS	PIO RS	WL RS
Deny WEZ (main task)	Adequate	5	2	-
Pursue KIO criteria (additional)	Adequate	-	2	5
Pursue altitude for vertical maneuver (additional)	Adequate	-	2	4
Pursue joker fuel (additional)	Adequate	-	2	6

Table 33: Test Results of TP 4.6 / 5.2

During defensive BFM setups, test aircraft performed radius fight against bandit, maintaining approximately 140 KIAS. While executing best BFM, test pilot also tried to comply with additional tasks.

Defensive BFM was the most challenging part throughout the test flight. First, test pilot had to be very aware of the levels of light buffet and medium buffet to be able to pull the stick at the very effective and critical boundary of a/c. Test pilot had difficulty to recognize this boundary and reiterated setups for three times. One set up concluded with stall and was recovered easily with knock it off. The other setups were hardly taken to pulling position although adversary was a L29 (thrust limited). Performance was inside adequate limits and handling quality rating due to CHRS was assessed 5. Undesirable motions tended to occur when pilot initiated abrupt maneuvers or attempted tight control during radius fight, but these motions could be prevented or eliminated by pilot technique rated to be 2 according to PIO RS.

Workload was significantly higher than offensive BFM when comparing relative additional tasks due to nature of defensive BFM as test pilot had to look outside and back portion. The prominent factor of seeing required information from either primary instrument, important gauges (like fuel quantity) came to consideration unless test pilot wasn't informed with aural alert function of monitored parameters. Workload rating was shown in 5th column of Table 33. It was hard to change test pilot's FOV from adversary at the back to PFD / MFD to assess additional task readings. They could all be complied within adequate limits. Especially, it was very hard to read fuel level from a minor writing in MFD as discussed in paragraph 2.1.3.

Minimum barometric altitude was set 6000 ft on ground to evaluate in setups if there would be any aural alert of “minimums, minimums” but test pilot couldn’t hear that alert while penetrating 6000 ft MSL.

L39 could give student pilots a good learning of how to use geometry to extend or shorten the distance between bandit and own aircraft, changing plane of motion and lead / pure / lag positioning to deploy WEZ or deny WEZ. Test aircraft could be capable of teaching basic mechanics of BFM (roll, turn, accelerate). Student pilots should be very aware of light and medium buffets of the aircraft to be able pull L39 to maneuver at limit boundaries. It would take time to learn this feature of aircraft even it is not representative to 5th generation systems as they use digital flight controls and have very different handling quality capabilities which student pilots should effort to get used to after attending following course.

As 5th generation aircrafts use network centric based technology, involving sensors, helmet mounted systems, fused information, they could employ high of bore sight missiles that would change some tactics used in basic fighter maneuvers. L39 would not be expected to comply with these new features but expected to show at least a digital range according to adversary simulating radar ranging, to materialize DLZ (dynamic launch zone) for IR (infra red) missiles, HUD (head up display) cues for gun tracking based on range of preceding aircraft. Those limited but essential features would help student pilots’ transition to 5th generation platforms.

Avionics coating would support L39’s BFM efficiency but should be improved. During defensive fights, student pilots could get difficulty to grab important readings at a very short time glance. The prominent ones should be to read easily like fuel quantity, airspeed, altitude, engine parameters. Furthermore, there should be some pilot defined limit aural alerts for altitude and fuel level to be able to have the information of approaching floor, coming joker or may be bingo fuel. If these kinds of features could be established to L39, COAF student pilots could focus on difficult to comprehend BFM mechanics more instead of sacrificing mission requirements to pursue safety parameters.

L39 was assessed UNSATISFACTORY (CLASS II) by means of lack of ranging capability to adversary, lack of aural alerts for altitude and fuel, poor handling quality to conduct radius fight during defensive BFM.

L39 should be equipped with a ranging device either as a sensor or bilateral data link between BFM players and forged with weapon employment cueing system (HIGHLY DESIRABLE - EFFECTIVENESS).

L39’s avionics should be modified to give aural alert for predefined fuel and altitude level (HIGHLY DESIRABLE – EFFECTIVENESS / SAFETY).

Procurement activity (COAF) should consider impacts of poor handling qualities of L39 for pulling the stick at the thrust / lift boundary and compare its characteristics for transitioning to 5th generation aircraft (HIGHLY DESIRABLE – EFFECTIVENESS).

SECTION 3 Conclusions

3.1 General Conclusion

L39 was found to be unsuitable for LIFT mission as thought of a transition aircraft to 5th generation systems. Although it was not expected to have similar capabilities like a 5th generation aircraft by means of handling qualities and avionics, L39 was expected to contain ranging to adversary either with sensor or link to be able to give DLZ (dynamic launch zone) for missile or gun employment during offensive BFM, supportive avionics features to ease altitude and fuel pursue and representative and easy handling quality during radius fight in BFM.

3.2 Unacceptable

N/A

3.3 Unsatisfactory (Class II)

1. L39 was assessed UNSATISFACTORY (CLASS II) by means of lack of ranging capability to adversary, lack of aural alerts for altitude and fuel, poor handling quality to conduct radius fight during defensive BFM.

3.4 Unsatisfactory (Class III)

1. L39 was assessed UNSATISFACTORY (CLASS III) considering minor but annoying lack of quick disconnect function of oxygen hose, stick backward tendency and warning / caution test button position of zone 2.
2. Garmin G3X small fuel quantity reading in all pages was assessed UNSATISFACTORY (CLASS III).
3. Low damped Dutch roll mode of L39 below air-to-air phase and Level 1 Category A Class IV minimum limit of MIL-F-8785C [5] was assessed as UNSATISFACTORY (CLASS III).
4. L39's avionics coating contribution to formation flight was assessed UNSATISFACTORY (CLASS III).

3.5 Satisfactory

1. L39's inside and outside FOV was assessed SATISFACTORY due to displays' position inside of optimum FOV and sufficient space found to be for outside FOV regarding AITOFF plot and qualitative evaluation of test pilot.
2. Within the scope of the test, ACMI debriefing software capabilities was assessed SATISFACTORY due to significant effect to increase BFM training efficiency.
3. L39's stall performance having 3.4% stall speed deviation from AFM data, aircraft's sufficient stall approach indications, benign stall characteristics and easy recovery feature were assessed SATISFACTORY.
4. L39 was assessed SATISFACTORY for intended LIFT mission with 2% acceptable deviation in best rate of climb speed and 0.8% acceptable deviation in best rate of climb

comparing to AFM data.

5. L39's maneuver performance was assessed as SATISFACTORY comparing with its AFM to be inside limit of 10%.
6. L39's longitudinal static stability was assessed SATISFACTORY with perceptible forces and stable force curves.
7. L39's heavily damped (deadbeat) short period mode characteristics and long period mode with mild and long enough period of free response was evaluated as SATISFACTORY.
8. L39's lateral-directional static stability with increasing rudder and aileron force due to sideslip angle and tendency to recover from wings level and steady heading sideslip conditions were assessed as SATISFACTORY.
9. L39's roll performance with sufficient lateral control power, roll rate and roll response was assessed as SATISFACTORY.
10. L39's longitudinal maneuvering stability with linear and sufficient stick force gradients was assessed as SATISFACTORY.

SECTION 4 Recommendations

4.1 Specific Recommendation

Due to COAF requirements mentioned in FTO [1] about recommendation display menu selection during BFM setups should be forged as primary instruments occupying whole screen for PFD, including G meter put on right side of HSI and split screen comprise of map and traffic menus for MFD as depicted in Figure 36.

Figure 36: PFD / MFD Page Recommendation

4.2 General Recommendation

COAF should assess focused on deficiencies of incapability of L39 for ranging, difficulties during defensive BFM especially in radius fight about not to have supporting elements for altitude and joker / bingo alerts, difficult and not representative handling qualities during maneuvering on the edge of lift / thrust boundaries that could affect transition to 5th generation aircrafts. COAF should consider of impacts that could have negative contributions to LIFT mission like physical input difficulties to avionics while flying close formation, stick lean back attitude on ground, oxygen hose quick-disconnect incapability, warning / caution test button's zone 2 position in case of emergency situations. COAF should also think of covering proposed MIL-F-8785C requirements.

4.3 Essential

N/A

4.4 Highly Desirable

1. L39 should be equipped with a ranging device either as a sensor or bilateral data link between BFM players and forged with weapon employment cueing system (HIGHLY DESIRABLE - EFFECTIVENESS).
2. L39's avionics should be modified to give aural alert for predefined fuel and altitude level (HIGHLY DESIRABLE – EFFECTIVENESS / SAFETY).

3. Procurement activity (COAF) should consider impacts of poor handling qualities of L39 for pulling the stick at the thrust / lift boundary and compare its characteristics for transitioning to 5th generation aircraft (HIGHLY DESIRABLE – EFFECTIVENESS).

4.5 Desirable

1. Student pilots should be exposed to simulated contingencies about ground evacuation and before take-off controls (control of trim tabs) to be implemented into their pilot operation checklists, SOPs, and flight briefings (DESIRABLE-SAFETY).
2. A CRM contract and SOP should be forged with maintenance personnel in order not to be close to ailerons during hot cockpit ground operations (DESIRABLE-SAFETY).
3. Warning / caution test button position should be moved to zone 1 as it should be interpreted as emergency controls (DESIRABLE-SAFETY).
4. A fuel low aural alert feature for pilot determined value should be added to software of Garmin G3X due to its difficulty in reading fuel quantity value in all pages (DESIRABLE - EFFECTIVENESS / SAFETY).
5. Display menu selection during BFM setups should be forged as primary instruments occupying whole screen for PFD, including G meter put on right side of HSI and split screen comprise of map and traffic menus for MFD (DESIRABLE - EFFECTIVENESS).
6. Further testing should be done with onboard FTI to comply with paragraph 3.4.2.1.1.2 of MIL-F-8785C [5] which was warning range for accelerated stalls (DESIRABLE - EFFECTIVENESS).
7. Further testing should be done with onboard FTI to discriminate breakout and friction forces (DESIRABLE - EFFECTIVENESS).
8. Further testing should be done to comply with dynamic characteristics and damping of control systems, characteristics of secondary control systems and pitch control force variations during rapid speed changes, paragraphs 3.5.3, 3.5.3.1, 3.6 and 3.2.1.1.2 of MIL-F-8785C [5] (DESIRABLE - EFFECTIVENESS).
9. Further testing should be performed with an onboard FTI capable of measuring control forces and displacements as well as the sideslip angle for further analysis before procurement (DESIRABLE - EFFECTIVENESS).
10. Procuring activity (COAF) should assess consequences and impacts of Level 2 Dutch role mode before agreement (DESIRABLE - EFFECTIVENESS).
11. Further tests should be done to satisfy procurement agency to comply with paragraphs 3.3.2.2, 3.3.2.3, 3.3.2.4, 3.3.2.5, 3.3.2.6 and 3.3.4.1.1 of MIL-F-8785C [5] (DESIRABLE - EFFECTIVENESS).
12. Further tests should be reiterated with onboard FTI to get exact aileron forces (DESIRABLE - EFFECTIVENESS).
13. Further testing should be reiterated with an onboard FTI capable of measuring control forces and displacements for further analysis before procurement (DESIRABLE - EFFECTIVENESS).
14. Further testing should be performed with an onboard FTI capable of measuring control forces and displacements for paragraph 3.2.3.1 longitudinal control in unaccelerated flight, paragraph 3.2.3.2 longitudinal control in maneuvering flight and paragraph 3.2.2.2.2 control motions in maneuvering flight derived from MIL-F-8785C [5]

(DESIRABLE - EFFECTIVENESS).

15. HOTAS capability should be coated to L39 (DESIRABLE-EFFECTIVENESS) to be able transmit from both radios.
16. Pre-set frequency capability should be brought to L39's avionics system (DESIRABLE-EFFECTIVENESS).
17. Any physical inputs to aircraft's avionics system should be emphasized by extending distance from lead aircraft during close formation in SOP of COAF (DESIRABLE-EFFECTIVENESS).

SECTION 5 Specification Compliance

Paragraph #	Description	Compliance
3.4.2.1.1 Stall Approach	The stall approach shall be accompanied by an easily perceptible warning consisting of shaking of the cockpit controls, buffeting, or shaking of the airplane, or a combination of both. The onset of this warning shall occur within the ranges specified in 3.4.2.1.1.1 and 3.4.2.1.1.2 but not within the Operational Flight Envelops. The increase in buffeting intensity with further increase in angle of attack shall be sufficiently marked to be noted by the pilot. The warning shall continue until the angle of attack in reduced to a value less than that for warning onset. At all angles or attack up to the stall, the cockpit controls shall remain effective in their normal sense, and small control inputs shall not result in departure from controlled flight. Prior to the stall, uncommanded oscillations shall not be objectionable to the pilot.	Level 1
3.4.2.1.1.1 Warning Speed for Stalls at 1g Normal to The Flight Path	Warning onset for stalls at 1g normal to the flight path shall occur between the following limits when the stall is approached gradually: Minimum Speed for Onset: Higher of 1.05Vs or VS + 5 knots Maximum Speed for Onset: Higher of 1.15Vs or VS + 1.5 knots	Level 1
3.4.2.1.1.2 Warning range for accelerated stalls.	Onset of stall warning shall occur outside the Operational Flight Envelope associated with the Airplane Normal State and within the following range or percentage of lift at stall at that airspeed, in that Airplane State, when the stall is approached gradually: Minimum Lift at Onset: 75% CL stall, Maximum Lift at Onset: 90% CL stall.	Further testing
3.4.2.1.2 Stall Characteristics	In the unaccelerated stalls of 3.4.2.1, the airplane shall not exhibit rolling, yawing or downward pitching at the stall which cannot be controlled to stay within 30 degrees for Class IV airplanes. It is desired that no pitch up tendencies occur in unaccelerated or accelerated stalls. In unaccelerated stalls, mild nose-up pitch may be acceptable if no pitch control force reversals occurs and if no dangerous, unrecoverable, or objectionable flight conditions result. A mild nose-up tendency may be acceptable in accelerated stalls if the operational effectiveness of the airplane is not compromised and: a. The airplane has adequate stall warning. b. Pitch control effectiveness is such that it is possible to stop the pitch up promptly and reduce the angle of attack, and c. At no point during the stall, stall approach or recovery does any portion of the airplane exceed structural limit load. The requirements apply for all stalls, including stalls entered abruptly.	Level 1
3.4.2.1.3 Stall Prevention and Recovery	It shall be possible to prevent the stall by moderate use of the pitch control alone at the onset of the stall warning. It shall be possible to recover from a stall by simple use of the pitch, roll and yaw control with cockpit control forces not to exceed those of 3.4.4.1, end to	Level 1

	regain level flight without excessive loss of altitude or build-up of speed. Throttles shall remain fixed until speed has begun to increase and an angle of attack below the stall has been regained unless compliance would result in exceeding engine operating limitations. In the straight-flight stalls of 3.4.2.1, with the airplane trimmed at an airspeed not greater than 1.4Vs, pitch control power shall be sufficient to recover from any attainable angle of attack.	
3.5.2.1 Control Centering and Breakout Forces	Longitudinal, lateral, and directional controls should exhibit positive centering in flight at any normal trim setting. Although absolute centering is not required, the combined effects of centering, breakout force, stability and force gradient shall not produce objectionable flight characteristics, such as poor precision-tracking ability, or permit large departures from trim conditions with controls free. Breakout forces, including friction, preload, etc., shall be within the limits: Min pitch 0.5, roll 0.5, yaw 1 lbf. Max pitch 3, roll 2, yaw 7 lbf.	Level 1
3.5.2.2 Cockpit Control Free Play	The free play in each cockpit control, that is, any motion of the cockpit control which does not move the control surface in flight, shall not result in objectionable flight characteristics, particularly for small-amplitude control inputs.	Level 1
3.5.3 Dynamic characteristics	A linear or smoothly varying airplane response to cockpit-control deflection and to control force shall be provided for all amplitudes of control input. The response of the control surfaces in flight shall not lag the cockpit-control force inputs by more than the angles specified in table XIII, for frequencies equal to or less than-the frequencies specified in table XIII.	Further testing
3.5.3.1 Damping	All control system oscillations shall be well damped, unless they are such of an amplitude, frequency, and phasing that they do not result in objectionable oscillations of the cockpit controls or the airframe during abrupt maneuvers and during flight in atmospheric disturbance.	Further testing
3.6 Characteristics of secondary control systems	Paragraphs 3.6.1, 3.6.2, 3.6.3, 3.6.4.	Further testing
3.2.1.1 Longitudinal Static Stability	For Levels 1 and 2 there shall be no tendency for airspeed to diverge aperiodically when the airplane is disturbed from trim with the cockpit controls fixed and with them free. This requirement will be considered satisfied if the variations of pitch control force and pitch control position with airspeed are smooth and the local gradients stable, with: a. Trimmer and throttle controls not moved from the trim settings by the crew, and b. 1g acceleration normal to the flight path, and c. Constant altitude over a range about the trim speed of ±15 percent or ±50 knots equivalent airspeed, whichever is less (except where limited by the boundaries of the Service Flight Envelopes). Alternatively, this	Level 1

	requirement will be considered satisfied if stability with respect to speed is provided through the flight control system, even though the resulting pitch control force and deflections may be zero. In no event shall its time to double amplitude be less than 6 seconds.	
3.2.1.1.2 Pitch control force variations during rapid speed changes	When the airplane is accelerated and decelerated rapidly through the operational speed range and through the transonic speed range by the most critical combination of changes in power, actuation of deceleration devices, steep turns and pullups, the magnitude and rate of the associated trim change shall not be so great as to cause difficulty in maintaining the desired load factor by normal pilot techniques.	Further testing
3.2.2.1 Short-Period Response	The short-period response of angle of attack which occurs at approximately constant speed, and which may be produced by abrupt pitch control inputs, shall meet the requirements of 3.2.2.1.1 and 3.2.2.1.2. These requirements apply, with the cockpit control free and with it fixed, for responses of any magnitude that might be experienced in service use. If oscillations are nonlinear with amplitude, the requirements shall apply to each cycle of the oscillation.	Level 1
3.2.1.2 Phugoid Stability	The long-period oscillations which occur when the airplane seeks a stabilized airspeed following a disturbance shall meet the following requirements: a. Level 1 ----- damping at least 0.04. b. Level 2 ----- damping at least 0.	Level 1
3.2.2.2.1 Control Forces in Maneuvering Flight	At constant speed in steady turning flight, pullups and pushovers, the variation in pitch controller force with steady-state normal acceleration shall have no objectionable nonlinearities within the following load factor ranges: Min: 0.5 g, Max: 3 g. All local force gradients shall be within the limits of table V. In additions, Fs /nz should be near the Level 1 upper boundaries of table V for combinations of high frequency and low damping. The term gradient does not include that portion of the force versus nz curve within the breakout force. Max gradient: 56/(nL-1), min gradient: 21/(nL-1)	Level 1
3.2.2.2.2 Control Motions in Maneuvering Flight	For all types of pitch controllers, the control motions in maneuvering flight shall not be so large or so small as to be objectionable. For Category A Flight Phases, the average gradient of pitch-control force per unit of pitch-control deflection at constant speed shall not be less than 5 pounds per inch for center-stick controllers for Levels 1 and 2.	Further testing
3.2.2.3.2 Control Feel	The deflection of the pilot's control must not lead the control force throughout the frequency range of pilot control inputs. In addition, the peak pitch control forces developed during abrupt maneuvers shall not be objectionably light, and the buildup of control force during the maneuver entry shall lead the buildup of normal acceleration.	Level 1

3.2.3.1 Longitudinal control in unaccelerated flight	In erect unaccelerated flight at all service altitudes, the attainment of all speeds between Vs and Vmax shall not be limited by the effectiveness of the longitudinal control or controls.	Further testing
3.2.3.2 Longitudinal control in maneuvering flight	Within the Operational Flight Envelope, it shall be possible to develop, by use of the pitch control alone, the following range of load factors: Levels 1 and 2 ----- no(-) to no(+)	Further testing
3.2.3.7 Longitudinal control in sideslips	With the airplane trimmed for straight, level flight with zero sideslip, the pitch-control force required to maintain constant speed in steady sideslips with up to 50 pounds of pedal force in either direction shall not exceed the pitch-control force that would result in a 1 g change in normal acceleration. In no case, however, shall the pitch-control force exceed: Center-stick controllers ----- 10 pounds pull to 3 pounds push.	Level 1
3.3.5 Directional Control Characteristics	Directional stability and control characteristics shall enable the pilot to balance yawing moments and control yaw and sideslip. Sensitivity to yaw control pedal forces shall be sufficiently high that directional control and force requirements can be met, and satisfactory coordination can be achieved without unduly high pedal forces, yet sufficiently low that occasional improperly coordinated control inputs will not seriously degrade the flying qualities.	Level 1
3.3.6.1 Yawing Moments in Steady Sideslips	For sideslips specified in 3.3.6, right yaw-control pedal deflection and force shall produce left sideslips and left yaw-control-pedal deflection and forces shall produce right sideslips. For Levels 1 and 2 the following requirements shall apply. The variation of sideslip angle with yaw-control-pedal deflection shall be essentially linear for sideslip angles between +15 degrees and - 15 degrees. For larger sideslip angles, an increase in yaw-control-pedal deflection shall always be required for an increase in sideslip. The variation of sideslip angle with yaw-control-pedal force shall be essentially linear for sideslip angles between +10 degrees and -10 degrees. Although a lightening of pedal force is acceptable for sideslip angles outside this range, the pedal force shall never reduce to zero.	Level 1
3.3.6.2 Side Forces in Steady Sideslips	For the sideslips of 3.3.6 and increase in right bank angle shall accompany an increase in right sideslip, and an increase in left bank angle shall accompany an increase in left sideslip.	Level 1
3.3.6.3 Rolling Moments in Steady Sideslips	For the sideslips of 3.3.6, left roll-control deflection and force shall accompany left sideslips, and right roll-control deflection and force shall accompany right sideslips. For Levels 1 and 2, the variation of roll-control deflection and force with sideslip angles shall be essentially linear.	Level 1
3.3.6.3.2	For Levels 1 and 2, positive effective dihedral (right roll control for right sideslip and left roll control for left sideslip) shall never be so great that more than 75 percent of roll control power available to the	Level 1

Positive Effective Dihedral Limit	pilot, and no more than 10 pounds of roll-stick force is required for sideslip angles which might be experienced in service employment.	
3.3.1.1 Lateral-Directional Oscillations (Dutch roll)	The frequency and damping ratio of the lateral-directional oscillations following a yaw disturbance input shall exceed the minimum values in table VI (Figure 29). The requirements shall be met in trimmed and in maneuvering flight with cockpit controls fixed and with them free, in oscillations of any magnitude that might be experienced in operational use. If the oscillation is nonlinear with amplitude, the requirement shall apply to each cycle of the oscillation. In calm air residual oscillations may be tolerated only if the amplitude is sufficiently small that the motions are not objectionable and do not impair mission performance.	Level 2
3.3.1.2 Roll Mode	The roll-mode time constant, tR, shall be no greater than the appropriate value in table VII (1 sec).	Level 1
3.3.2.2 Roll rate oscillations	Following a yaw-control-free step roll control command, the roll rate at the first minimum following the first peak shall be of the same sign and not less than the following percentage of the roll rate at the first peak: (60%) For all Levels, the change in bank angle shall always be in the direction of the roll control command. The roll command shall be held fixed until the bank angle has changed at least 90 degrees.	Further testing
3.3.2.3 Bank angle oscillations	The value of the parameter ϕosc/ϕav following a yaw-control-free impulse roll control command shall be within the limits as shown on figure 5 for Levels 1 and 2. The impulse shall be as abrupt as practical within the strength limits of the pilot and the rate limits of the roll control system.	Further testing
3.3.2.4 Sideslip excursions	Following a yaw-control-free step roll control command, the ratio of the sideslip increment, Δβ, to the parameter k (6.2.6) shall be less than the values specified herein. The roll command shall be held fixed until the bank angle has changed at least 90 degrees.	Further testing
3.3.2.5 Control of sideslip in rolls	In the rolling maneuvers described in 3.3.4, but with coordination allowed for all Classes, directional-control effectiveness shall be adequate to maintain zero sideslip with pedal force not greater than 50 pounds for Class IV airplanes in Flight Phase Category A, Level 1, and 100 pounds for all other combinations of Class, Flight Phase Category and Level.	Further testing
3.3.2.6 Turn coordination	It shall be possible to maintain steady coordinated turns in either direction, using 60 degrees of bank for Class IV airplanes, 45 degrees of bank for Class I and II airplanes, and 30 degrees of bank for Class III airplanes, with a pedal force not exceeding 40 pounds. It shall be possible to perform steady turns at the same bank angles with yaw controls free, with a roll stick force not exceeding 5 pounds or a roll wheel force not exceeding 10 pounds. These requirements constitute Levels 1 and 2, with the airplane trimmed for wings-level straight flight.	Further testing

3.3.3 Pilot-induced oscillations	There shall be no tendency for sustained or uncontrollable lateral-directional oscillations resulting from efforts of the pilot to control the airplane.	Level 1
3.3.4.1 Roll Performance for Class IV Airplanes	Roll performance in terms of ϕt for Class IV airplanes is specified in table IXb. Additional or alternate roll performance requirements are specified in 3.3.4.1.1 and 3.3.4.1.2; these requirements take precedence over table IXb. Roll performance for Class IV airplanes is specified over the following ranges of airspeeds: (1.3 sec for 90°)	Level 1
3.3.4.1.1 Roll Performance in Flight Phase CO	Roll performance for Class IV airplanes in Flight Phase CO is specified in table IXc in terms of ϕt for 360' rolls initiated at 1 g, and in table IXd for rolls initiated at load factors between 0.8no (-) and 0.8no (+).	Further testing
3.3.4.1.3 Roll Response	Stick-controlled Class IV airplanes in Category A Flight Phase shall have a roll response to roll control force not greater than 15 degrees in 1 second per pound for Level 1, and not greater than 25 degrees in 1 second per pound for Level 2. In case of conflict between the requirements of 3.3.4.1.3 and 3.3.4.3, the requirements of 3.3.4.1.3 shall govern. The term sensitivity does not include breakout force.	Level 1
3.3.4.3 Roll Control Forces	The stick or wheel force required to obtain the rolling performance specified in 3.3.4, 3.3.4.1 and 3.3.4.2 shall be neither greater than the maximum in table X nor less than the breakout force plus: a. Level 1---------- one-fourth the values in table X (20 lb)	Level 1
3.3.4.4 Linearity of Roll Response	There shall be no objectionable nonlinearities in the variation of rolling response with roll control deflection or force. Sensitivity or sluggishness in response to small control deflections or force shall be avoided.	Level 1

ANNEX A Aircraft Description

A.1 L39 AFM

To be submitted as a separate folder (T.O. 1T-L39C-1, “Flight Manual L39C Aircraft”, Rev 0).

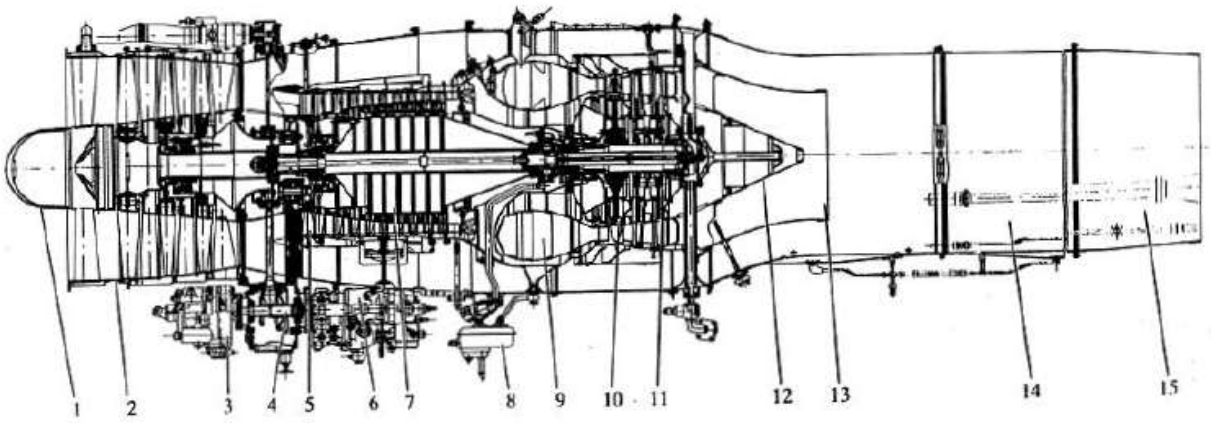
A.2 Engine

The aircraft was thrusted by an Al-25TL engine which developed approximately 16.9 kN (3800 lb) static thrust, on a standard day at sea level. The engine was a twin shaft bypass turbofan with a three-stage low pressure (LP) axial flow compressor and a nine-stage high pressure (HP) axial flow compressor. The LP compressor was driven by a two-stage axial turbine. The HP compressor was driven by a single stage axial turbine. The air flowing through the LP compressor diverged into two concentric flows:

- The primary inner hot flow, which was routed through variable inlet guide vanes, compressed by the HP compressor before reaching the combustion chamber.
- The secondary, by-pass flow, which was directed to the by-pass exhaust through a mixer, where the inherent energy of this flow is convened into kinetic energy.

Engine bleed air, taken from the nineth stage of the HP compressor, was employed for cabin ECS and pressurization, de-icing and demisting of transparent surfaces, pressurizing anti-G suits, fuel transfer from tip tanks and from invented flight tank and for engine anti-icing.

Two surge bleed valves prevented the HP compressor from surging at low rotation speeds. These surge bleed valves were spring valves that open below 86-89% RPM of the third compressor stage and 74-77% of the fifth stage. The engine was equipped with an annular combustion chamber containing 12 main fuel nozzles and two spark plugs were provided for engine starting. The engine cross section was shown in Figure 37.



1. Inlet Directing Body (IDB)
2. LPC Rotor
3. Fuel Pump
4. Gear Box
5. HPC Inlet Directing Body
6. Fuel Regulator/Governor
7. HPC Rotor
8. Waste Tank
9. Combustion Chamber
10. HP Turbine Rotor
11. LP Turbine Rotor
12. Inner Core
13. Inner Stream Jet Nozzle
14. Extension Pipe
15. Nozzle

Figure 37: Engine Cross Section

A.3 Oxygen System

The aircraft was equipped with a gaseous oxygen system which was divided into high- and low-pressure subsystems. The system utilized 4 four-liter cylinders and 2 spherical two-liter bottles, installed in the nose compartment and an emergency oxygen container located in the seat pack of the parachute. In flight the emergency oxygen containers were in the ejection seat frame.

Each pilot received his oxygen supply through a separate pressure line, delivered from two cylinders one spherical bottle. However, when the pressure decreases, the lines could be interconnected so that the oxygen would be used to supply the other one. A pressure reducer in each circuit provided reduced oxygen pressure to the diluter demand regulator.

Both forward and aft pilots were equipped with an oxygen mask; the oxygen system installation in the forward cockpit had a provision to use an altitude compensating flight suit with hermitized pressure helmet.

The pilot breathed ambient air up to flight altitude 2000 m, from that altitude up to 8000 m a mixture of air and oxygen. The ratio between air and oxygen depends on the cabin altitude. From flight altitude 8000 m the pure oxygen was supplied to the mask. The mixture or oxygen was delivered to the mask either in dependence on pilot's breathing or pressurized pure oxygen could be continuously supplied if needed.

A.4 Armament System

The armament system provided the A/C with the capability to carry and deliver air to air and air to ground weapon types. The aircraft was equipped with a gyroscopic sight to aim the weapons and with a gun camera to shoot the weapon delivery. The system included the capability to jettison the stores in emergency. The armament system was protected and controlled by two "ARMS" C/Bs, one in the forward cockpit center pedestal and one in the aft cockpit miscellaneous C/B switch panel. Both C/Bs had to be switched ON to enable the system operation by the trigger located on the forward cockpit stick grip (except in emergency jettison operation). The stores releasing by the trigger was blocked up the ale speed 310 ± 15 km/h. The A/C had two external armament stations, one on each wing.

The weapon delivery system had the following main modes: bombs delivery in air to ground, rockets delivery for air to ground and air to air targets, missile launching in air to air and gun training mode in air to air (with gun camera).

To operate the armament system the following switches, have to be switched on:

- Forward cockpit main C/B switch panel
  - "BATTERY"
  - "ENGINE"

- Aft C/B switch panel
  - "CONTR."
  - "SIGNAL."
  - "EMERG. DROP"
  - “FIRE”
  - "FLT RECOR/EKSR-46/KL-39"

- Miscellaneous C/B switch panel
  - "NETW."
  - "SIGNAL."

The armament system controls were located on forward cockpit center pedestal, on main and miscellaneous C/B switch panel. Armament system status indication lights were in the forward cockpit on lower and upper armament indication panels and in the aft cockpit on left and right armament indication panels.

ANNEX B Flight Controls

B.1 Primary Flight Controls

The primary night controls (aileron, elevators, and rudder) were activated by push-pull rods and levers while the secondary fight controls (trim tabs, flaps and speed brakes) were controlled by either electric or hydraulic actuators. The aileron and elevator control systems consisted of two interconnected control sticks (forward and aft cockpits). The rudder control system consisted of two pairs of interconnected rudder pedals. The rudder pedals could be adjusted according to pilot needs by the pedal adjustment controller.

Aerodynamic balance of the ailerons and the elevator was obtained by balance tabs mounted on the trailing edge of the respective control surface. The elevator system was provided with a bungee booster. This bungee was activated by elevator deflection of approximately 13 degrees or more, to assist the pilot in overcoming the high stick forces at high speed and high G load.

The flight controls could be locked on the ground by means of a locking device shifted under the instrument panel. General view of cockpit control was given below Error! Reference source not found..

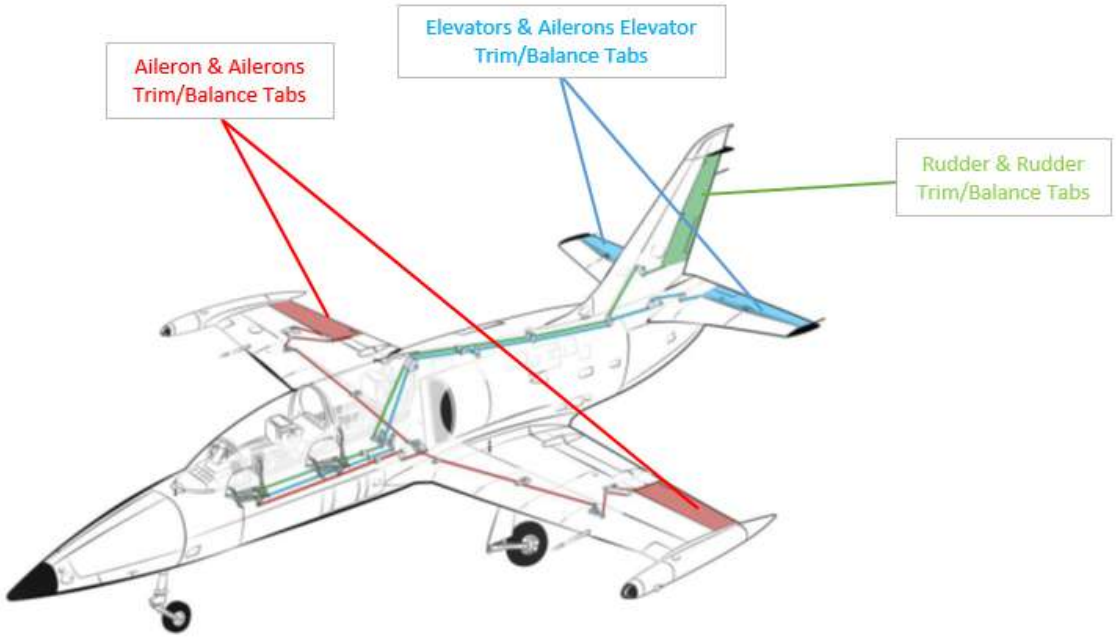


Figure 38: L39 Cockpit Controls

B.2 Trim

The trim tabs were provided aircraft trimming along the longitudinal and lateral axes.

Longitudinal trimming was provided by trim tabs fitted to the left and right elevators. The right trim tab was operated by electrical actuator which deflects the tab up or down. The left trim tab was controlled by the flaps extension and would deflect automatically when the wing flaps were moved from to 44 degrees (landing) position, thus effectively introducing a “nose up” trim for the flare. The right trim tab was controlled by the trim switch located on the control stick in either cockpit.

Lateral trimming was provided by combined trim / balance tab fitted to the left aileron and was operated by an electrical actuator which deflects the tab up or down. Right tab was balance tab.

Both longitudinal and lateral trimming were controlled by a five-position spring loaded switch located on the top of the control stick grip. In the forward cockpit, longitudinal trim position was indicated by an indicator consisting of a pointer and a top viewed miniature aircraft on a graduate scale. Consistent with the movement of the elevator tab, the pointer indicates a nose-up or nose-down attitude proportional to the amount of tab displacement. The indicator was located on the center pedestal. The aft cockpit indication consisted of a trim tab neutral position green indicating light, placard “LONGITUD”.

In both cockpits, lateral trim position indicator was a “Neutral Position” green light that illuminates when the aileron trim was at the neutral position. The light in the forward cockpit was labelled “NEUTRAL POSITION” and in the aft cockpit “LATERAL”

The lateral trim tabs control and indicating system was powered by 28 V and protected by “U/C BALANC” and “SIGNAL” circuit brakers, located on the aft circuit braker switch panel in the forward cockpit, and by “SIGNAL” circuit braker, located on the miscellaneous circuit braker switch panel in the aft cockpit. The longitudinal trim tab control and indicating system was powered and protected by the same manner as the lateral one, furthermore by the “ENGINE INSTRUM T&B INDIC” circuit braker on the aft circuit braker switch panel and “ENGINE” circuit braker located on the main circuit braker switch panel.

B.3 Flaps

The hydraulically operated and electrically controlled flaps were of the slotted fowler type. The two flaps were interconnected by a single actuating cylinder. Synchronization of both LH and RH flaps was established mechanically.

The flaps might be set to one of the three positions corresponding to the appropriate control button located on the LH console. Buttons in the aft cockpit button located on the LH console. Buttons in the aft cockpit override function of aft cockpit buttons. Each button bears a symbol which represents a different flight situation.

- The forward button, symbolized by a straight line, represents “Flight” position zero degrees.
- The centre button, symbolized a slight bent line, represents the “Take Off” position (25°).
- The aft button, symbolized by a sharp bent line, represents the “Landing” position (44°).

Opposite each button was an indicator light, bearing the corresponding symbol, that illuminates when the flaps had reached the desired setting. After executing the hydraulic function, the depressed button pops back to its initial position. The mechanical indicators, located on upper surface of each wing, provide visual identification of flaps position.

Controls and indication of the flaps system was identical in both cockpits. The flaps were automatically retracted to “Flight” position (zero degrees) at airspeed above 310±15 km/h. Flaps extension was blocked from the aircraft speed above 310±15 km/h.

Flaps control and position indication was powered by 28V and protected by the “U/C BALANC”, “SIGNAL” and “CONTR” circuit brakers, located on the aft circuit braker switch panel in the forward cockpit and by “SIGNAL” circuit braker located on miscellaneous circuit braker switch panel.

Moving the emergency flaps lever in either cockpit to the emergency position, causes the flaps to extend all the way to landing (44°) position. Moving the lever back to the initial forward position will retract the flaps. Both forward and aft levers had the same priority.

B.4 Speed Brakes

The hydraulically operated and electrically controlled speed-brakes were mounted on the wing’s lower side and consisted of two hinged panels which, when opened, extend 55° into the airstream.

Control from both cockpits was by means of a switch located on the throttle grip, Selecting the switch to its aft position would cause the speed brakes to extend. Selecting the switch to its forward position would retract the brakes.

The forward cockpit switch had tree positions (functions) forward (speed brakes retracted), aft (speed brakes extended) and pressing inward (tactical use – the speed brakes extend and remain extended if the switch was depressed. The moment the switch was released the speed brakes retract.

The spring loaded to the center position aft cockpit switch had three positions (functions). Momentary forward (speed brakes were retracted as long as the switch was held in forward position), momentary aft (speed brakes were extended as long as the switch was held in the aft position), center (enables the forward cockpit to maintain control over the speed brakes).

The speed brakes could control from the forward cockpit only if the aft switch was at neutral position. The aft switch had over-ride function (the speed brakes could be retracted / extended from the aft cockpit although the forward switch was in the opposite position.

Indication was identical in both cockpits and consisted of a green “AIR BRAKE OUT” light in the landing gear position indicator panel. Upon reaching the speed of M 0.78 ± 0.02, the speed brakes extend automatically and retract once the speed was reduced below this value, while extended the M_{MAX} light would be illuminated.

ANNEX C Test Aircraft and Aircrew

C.1 Test Aircraft Specifications

The Aero L39 Albatros was single engine, dual seater, and subsonic aircraft. The aircraft primary missions were basic and advanced training and light attack missions. Test aircraft's registration is CGFNO. Fuel Capacity is 1300 liters total.

The A/C dimensions under normal conditions of weight, shock absorber compression and tire inflation are as below:

- Wingspan 31,042 FT
- Overall length 39,805 FT
- Height 15,93 FT
- Wing area 202,381 FT^2
- Wing aspect ratio 5,2

Aircraft operating weights are:

- Empty weight 7.485 LBS (3.395 KG)
- Basic weight 7.640 LBS (3.465 KG)
- Max ramp weight 10.520 LBS (4.770 KG)
- Max landing weight 9.920 LBS (4.600 KG)
- Max. T/O weight 10.360 LBS (4.700 KG)

Aircraft CG limits are:

- Permissible CG 21 – 28 % MAC
- Front pilots eject CG 29.01 % MAC (Aircraft may still be landed from aft cockpit, make flapless landing, S/B can be used, final approach speed 125 KIAS)

Figure 39: Test Aircraft (L39, CGFNO)

FUEL SYSTEM	FUSELAGE TANK CAPACITY (USABLE)	1100 L
	TIP TANKS (2)	100 L EACH, 200 L
	TOTAL CAPACITY (USABLE)	1300 L
	INVERTED FLIGHT DURATION	20 SEC
	BETWEEN INVERTED FLIGHT	MIN 20 SEC
AIRSPEEDS	STALL SPEED, CLEAN	97 KIAS
	STALL SPEED, FLAP TO (25°)	89 KIAS
	STALL SPEED, FLAP LD (44°)	84 KIAS
	MAX GEAR SPEED	180 KIAS
	MAX FLAPS SPEED	175 KIAS (160 KIAS)
	BEST GLIDE SPEED	135 KIAS
	BEST RATE OF CLIMB SPEED	205 KIAS
	NEVER EXCEED SPEED	490 KIAS
	MACH NUMBER LIMIT	0.8 M

	MAX NO CANOPY SPEED	190 KIAS
	MAX CROSSWIND	20 KIAS
	MAX BRAKING SPEED	102 KIAS
	MAX TAXI TURNS SPEED	5 KIAS
	MAX ENGINE START TAIL WIND	20 KIAS
PERFORMANCE	TAKE-OFF ROLL	19 SEC / 1575 FT
	LANDING ROLL	26 SEC / 2065 FT
	INITIAL RATE OF CLIMB	4500 FT/MIN
	RATE OF CLIMB @16400 MSL	2480 FT/MIN
	TIME TO CLIMB @16400 MSL	5 MIN
	RATE OF CLIMB @32000 MSL	670 FT/MIN
	TIME TO CLIMB @32000 MSL	17 MIN
	TIME TO CLIMB @36000 MSL	35 MIN
	NORMAL CRUISE SPEED	300 KIAS
	MAX LEVEL SPEED (FL 200)	410 KIAS
	SERVICE CELLING	38700 MSL
RPM	IDLE	56 ± 1.5%
	BLEED VALVES RPM	74-77% & 86-89%
	CRUISE	99.6 ± 1%
	NOMINAL	103 ± 1%
	MAX (TAKE-OFF)	106.8 ± 1%
	MAX RPM (DURATION)	20 MIN
	MIN AUTOROTATION RPM FOR WINDMILLING START	15%

Table 34: Test Aircraft (L39) Limits

C.2 L39 Flight Checklist

To be submitted as a separate folder (ITTC L39 Normal / Emergency Procedures, Limitations and Performance Checklist, Rev2, 2020).

C.3 Garmin G3X Avionics System

The Garmin G3X avionics suite provided PFD and MFD displays that enabled test pilot and flight test engineers' practical opportunities to apply flight test techniques to avionics systems. Display units supported the implementation of user-developed displays, enabling development and testing of various options for display format, display layout, etc. to give the candidates realistic test situations, specifically to conduct tests on unapproved display layout.

The G3X touch system consists of the following Line Replaceable Units (LRUs):

- Two Garmin Display Unit (GDU) 460 in front cockpit
    - Single Display: Split Primary Flight Display (PFD) & Multi Function Display (MFD)

- Multiple Displays: PFD, MFD, or split screen
- Landscape orientation

Figure 40: GDU 460 Screen

Front cockpit was coated with two Garmin G3X GDU 460 wide screens. Left hand side display basically works as PFD comprise of primary instruments display and right-hand side works as a MFD for additional avionics capabilities. Both screens have the feature of splitting into two, left hand side holds the responsibility to always show primary instruments and right-hand side can generate multiple pages' display as a whole screen or map fixed on left part while right part can be rotary changeable during split screen feature activated. 9 subpages were introduced, MAP, CHT (enroute charts), WPT (waypoint), FPL (active FPL), WX (weather), TER (terrain), TRF (traffic), SXM (SiriusXM Audio - entertainment purpose), INFO (information - about GPS) and ENG (engine).

Figure 41: PFD Screen

Figure 42: MFD Screen

The G3X touch data card slot was used Secure Digital (SD) cards. The SD card could be used for software updates, checklist files, flight data logging, exporting track logs / user waypoints, and importing / exporting flight plans.

The flight data logging feature automatically stores critical flight and engine data on SD data card. 2 GB SD card could store over 1000 hours of flight data or up to 1000 files (whichever comes first).

The Attitude and Heading Reference System (AHRS) performed attitude, heading, and vertical acceleration calculations for the G3X touch system, utilizing GPS, magnetometer, and air data, in addition to information from its internal sensors. Attitude and heading information were updated on the PFD while the AHRS receives appropriate combinations of information from the external sensor inputs.

The AHRS (GSU 25D) corrected for shifts and variations in the earth's magnetic field by applying the magnetic field variation database. The magnetic field variation database was derived from the International Geomagnetic Reference Field (IGRF). The IGRF was a mathematical model that describes the earth's main magnetic field and its annual rate of change. The database was updated approximately every 5 years. Failure to update this database could lead to erroneous heading information being displayed to the pilot.

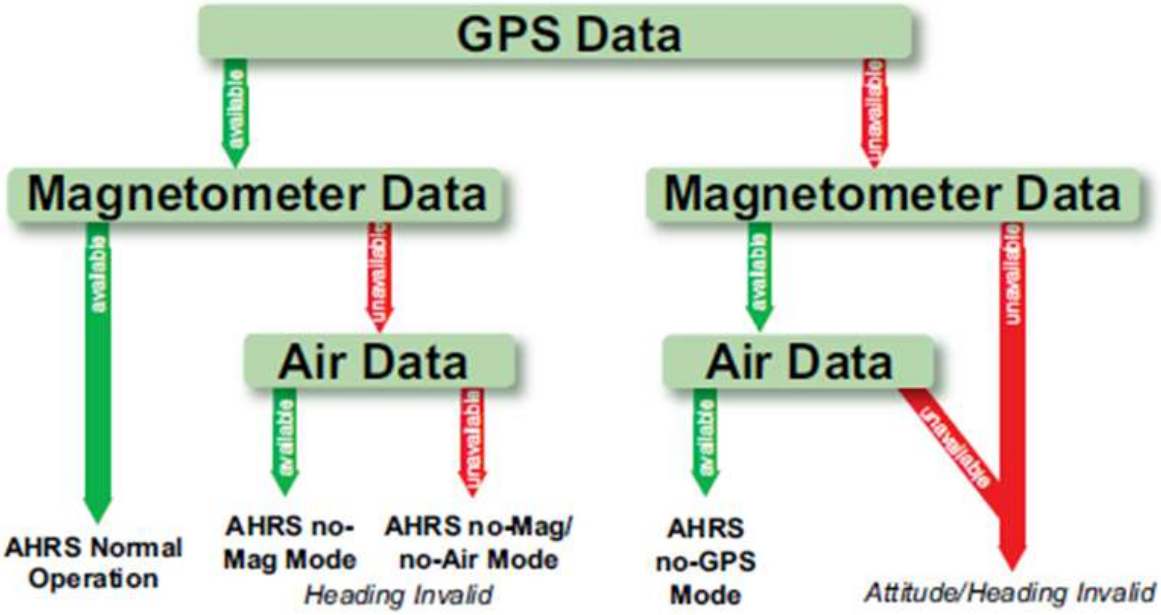


Figure 43: AHRS Overview

Increased situational awareness was provided by replacing the traditional instruments on the panel with an easy-to-scan Primary Flight Display (PFD) that features a horizon, airspeed, attitude, altitude, vertical speed, heading, and course deviation information. The following flight instruments and supplemental flight data were displayed on the PFD.

Figure 44: PFD Display

In addition to the flight instruments, the PFD also displayed various supplemental information, including the Outside Air Temperature (OAT), wind data, and Vertical Navigation (VNAV) indications.

The vertical navigation page provided settings for the vertical navigation feature. These settings created a three-dimensional profile from the present location and altitude to a final (target) altitude at a specified location.

The G3X Engine Instruments System (EIS) displayed engine, electrical, and other system parameters. Additional EIS information could be viewed by selecting the engine page on the MFD.

Figure 45: Engine Parameters Indication

The Crew Alerting System (CAS) messages displayed depend upon the current configuration and would vary from the examples listed below. CAS messages were grouped by criticality (warning, caution, advisory). The color of the message is based on its urgency and on required action:

- WARNING (red): Requires immediate attention.
- CAUTION (yellow): Requires pilot awareness and possible future corrective action.
- ADVISORY (white): Provides general information.

Communication / Navigation / Surveillance (CNS) system included the communication radios, navigation radios, and Mode S transponder. These functions could be accessed from the boxes that make up the CNS Data Bar located at the top of the PFD and/or MFD.

The COM Frequency box was composed of two fields; one active frequency was on the left side and the standby frequency is on the right.

Figure 46: CNS Interface

Flight planning on the G3X consisted of building a flight plan by entering waypoints one at a time and inserting approaches as needed. The flight plan was displayed on maps using different line widths, colors, and types, based on the type of leg and the segment of the flight plan currently being flown.

Up to 50 flight plans with up to 300 waypoints each could be created and stored in memory. One flight plan could be activated at a time and becomes the active flight plan. The active flight plan was erased when the destination was reached, and the system is turned off.

The terrain page displayed altitudes of terrain and obstructions relative to the aircraft position and altitude with reference to a database that may contain inaccuracies. Terrain and obstructions were shown only if they were in the database. Terrain and obstacle information should be used as an aid to situational awareness. They should never be used to navigate or maneuver around terrain.

The G3X Touch GPS receiver provided the horizontal position and altitude of the aircraft. Aircraft GPS altitude was derived from satellite position. GPS altitude was then converted to a mean sea level (MSL) based altitude (GPS-MSL altitude) and was used to determine terrain and obstacle proximity. GPS-MSL altitude accuracy was affected by satellite geometry but was not subject to variations in pressure and temperature that normally affected pressure altitude sensors. GPS-MSL altitude did not require local altimeter settings to determine MSL altitude. It was a widely used MSL altitude source.

Terrain and obstacle databases were referenced to MSL. Using the GPS position and altitude, terrain feature portrayed a 2D picture of the surrounding terrain and obstacles relative to the position and altitude of the aircraft. GPS position and GPS-MSL altitude were used to calculate and predict the aircraft's flight path in relation to the surrounding terrain and obstacles. In this way, the pilot could view predicted dangerous terrain and obstacle conditions.

Alert windows appeared on all pages (except terrain page) to inform the pilot of proximity to the terrain and obstacles, as well as an unsafe descent rate. These alerts depended on user-defined parameters in the terrain page setup.

The G3X Touch was compatible with three different traffic sources: TIS-A traffic via a Garmin Mode S Transponder, TAS via a GTS 800, or ADS-B/TIS-B traffic via a compatible ADS-B device. When the G3X Touch system was configured with both a Mode S transponder capable

of receiving TIS-A traffic and a compatible device capable of receiving ADS-B/TIS-B traffic the G3X Touch would automatically switch between traffic sources.

C.4 L39 Garmin EFIS Installation Supplement

To be submitted as a separate folder (ITPS-L39-FMS-G3X-001, "L39C Aircraft Flight Manual Supplement, Garmin EFIS Installation", Rev1, 2019).

C.5 Garmin Pilot's Guide

To be submitted as a separate folder (Garmin G3X Touch Pilot's Guide for Certified Aircraft, RevA, 2019).

C.6 Test Aircrew Experience

The test aircrews were Şükrü YILMAZ (TP) and Serkan DEMİR (FTE).

- Şükrü Yilmaz has over 3000 flight hours with 20 different aircraft types.
- Serkan Demir has 8 years of engineering experience in military and general aviation.

Figure 47: Test Pilot

Figure 48: Flight Test Engineer

C.7 Test Aircrew Anthropometric Data

Detailed percentiles of test pilot were given in Table 35 according to 2012 Canadian Forces Anthropometric Survey (CFAS) [2].

Acromial Height, Sitting (cm / %)	64/85	Acromion-Wall Depth (cm / %)	12/65
Acromial Height (cm / %)	148/70	Arm Length (cm / %)	66/80
Buttock-Knee Length (cm / %)	63/70	Biacromial Breadth (cm / %)	43/85
Eye Height, Sitting (cm / %)	80/35	Bieltoid Breadth (cm / %)	52/80
Thumbtip Reach (cm / %)	85/90	Bizygomatic Breadth (cm / %)	14.6/80
Stature (cm / %)	182/80		

Table 35: Detailed Percentiles of TP

Detailed percentiles of flight test engineer were given in Table 36 according to 2012 Canadian Forces Anthropometric Survey (CFAS) [2].

Acromial Height, Sitting (cm / %)	62/98	Acromion-Wall Depth (cm / %)	10/25
Acromial Height (cm / %)	143/40	Arm Length (cm / %)	63/45
Buttock-Knee Length (cm / %)	60/40	Biacromial Breadth (cm / %)	40/30
Eye Height, Sitting (cm / %)	78/20	Bieltoid Breadth (cm / %)	48/25
Thumb tip Reach (cm / %)	79/50	Bizygomatic Breadth (cm / %)	13.5/20
Stature (cm / %)	174/35		

Table 36: Detailed Percentiles of FTE

ANNEX D Scope of the Test

D.1 Weight and Balance Sheets

Annex D.1 Sortie 1 W& B.xlsx

Annex D.1 Sortie 2 W& B.xlsx

Annex D.1 Sortie 3 W& B.xlsx

ANNEX E Tests Made and Test Techniques

E.1 Flight Test Plan

To be submitted as a separate folder (Annex E.1 Flight Test Plan).

E.2 Test Matrix

Annex E.2 Test Matrix.xlsx

E.3 Test Cards

Annex E.3 TC Sortie 1.docx

Annex E.3 TC Sortie 2.docx

Annex E.3 TC Sortie 3.docx

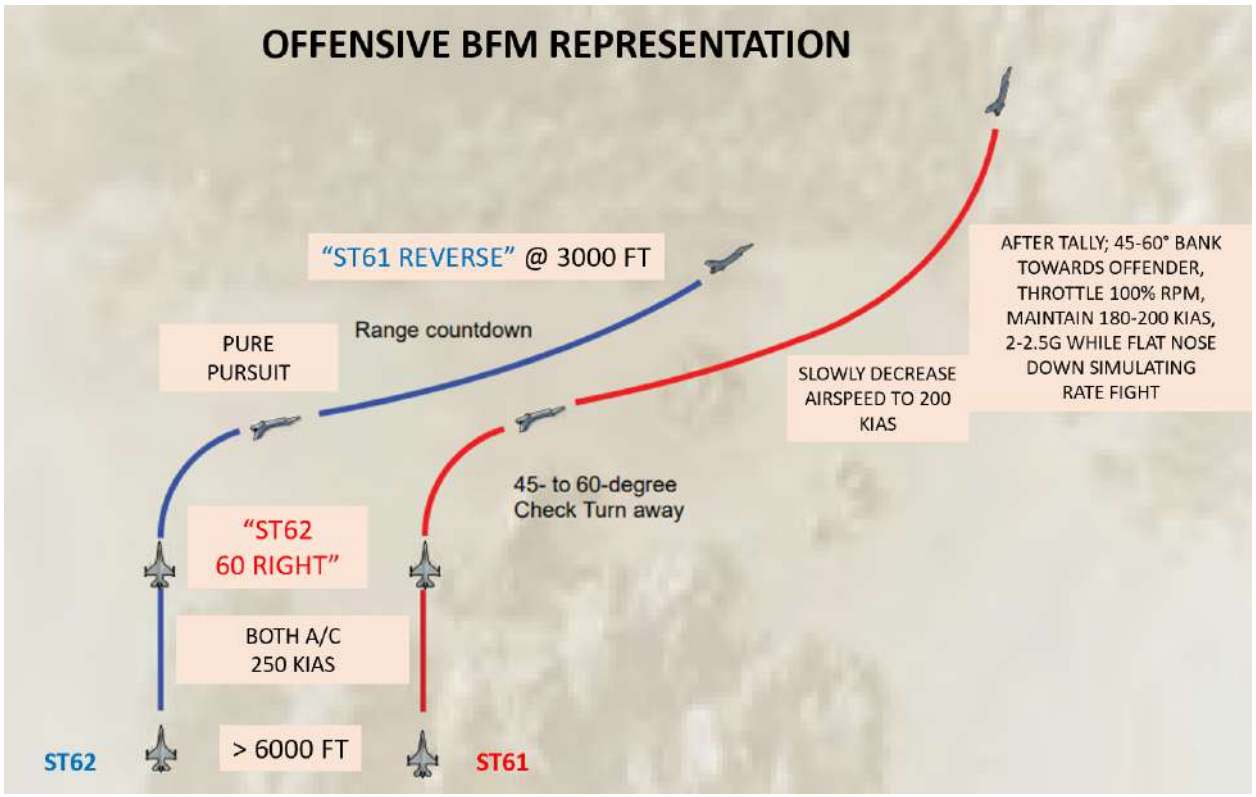
E.4 Post Flight Reports

Annex E.4 PFR Sortie 1.docx

Annex E.4 PFR Sortie 2.docx

Annex E.4 PFR Sortie 3.docx

E.5 Representative Offensive BFM Task



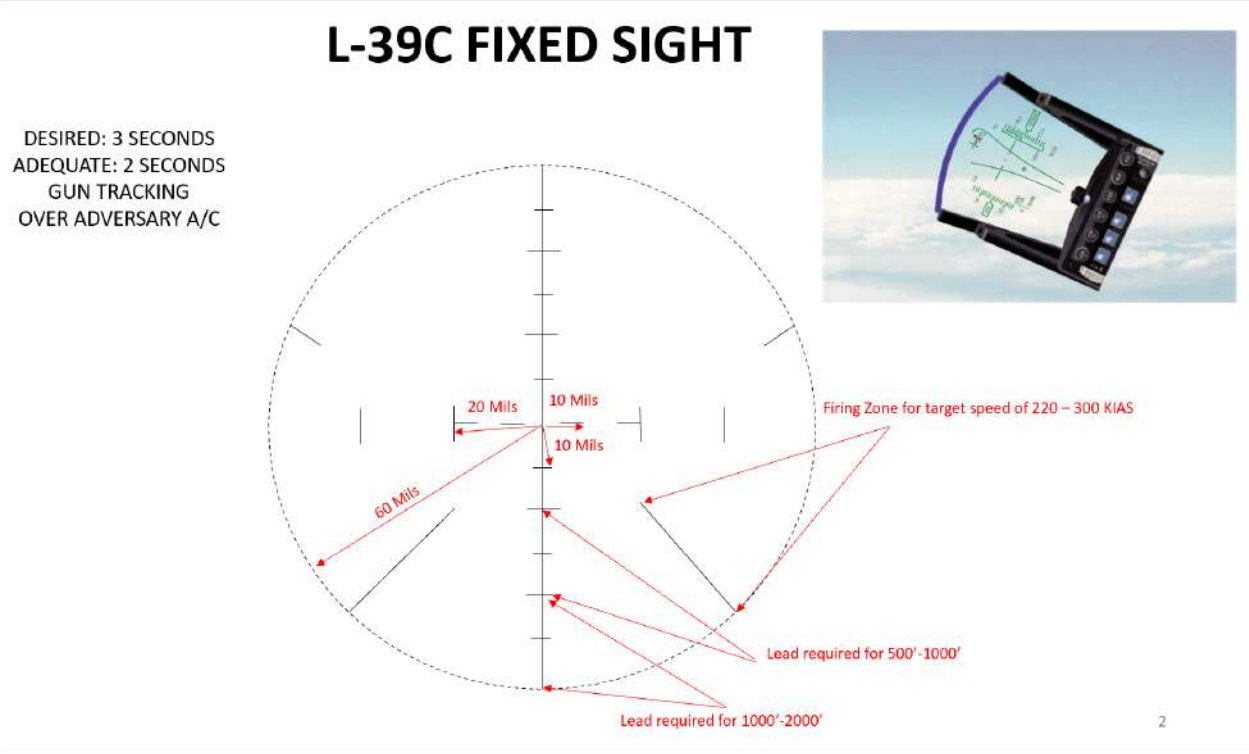


Figure 49: Representative Offensive BFM Task

E.6 Representative Defensive BFM Task

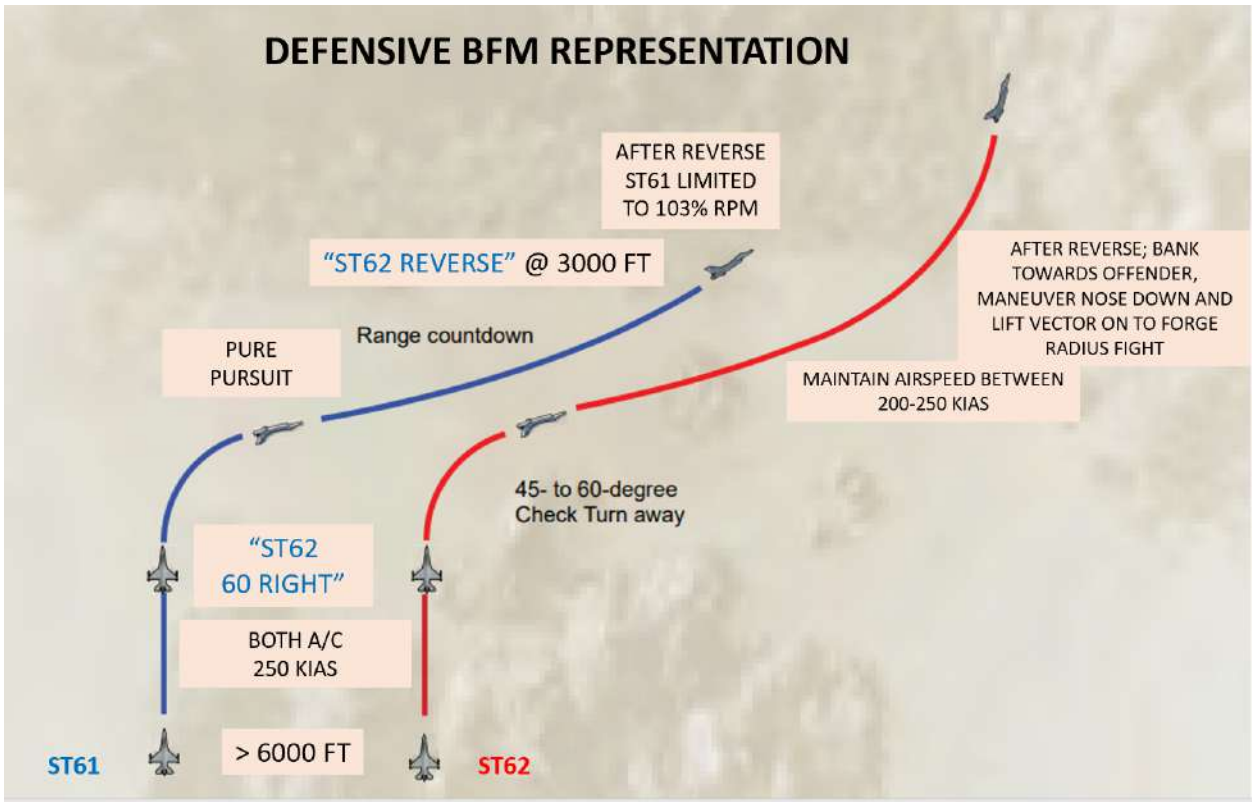


Figure 50: Representative Defensive BFM Task

E.7 Cooper Harper HQ Rating Scale

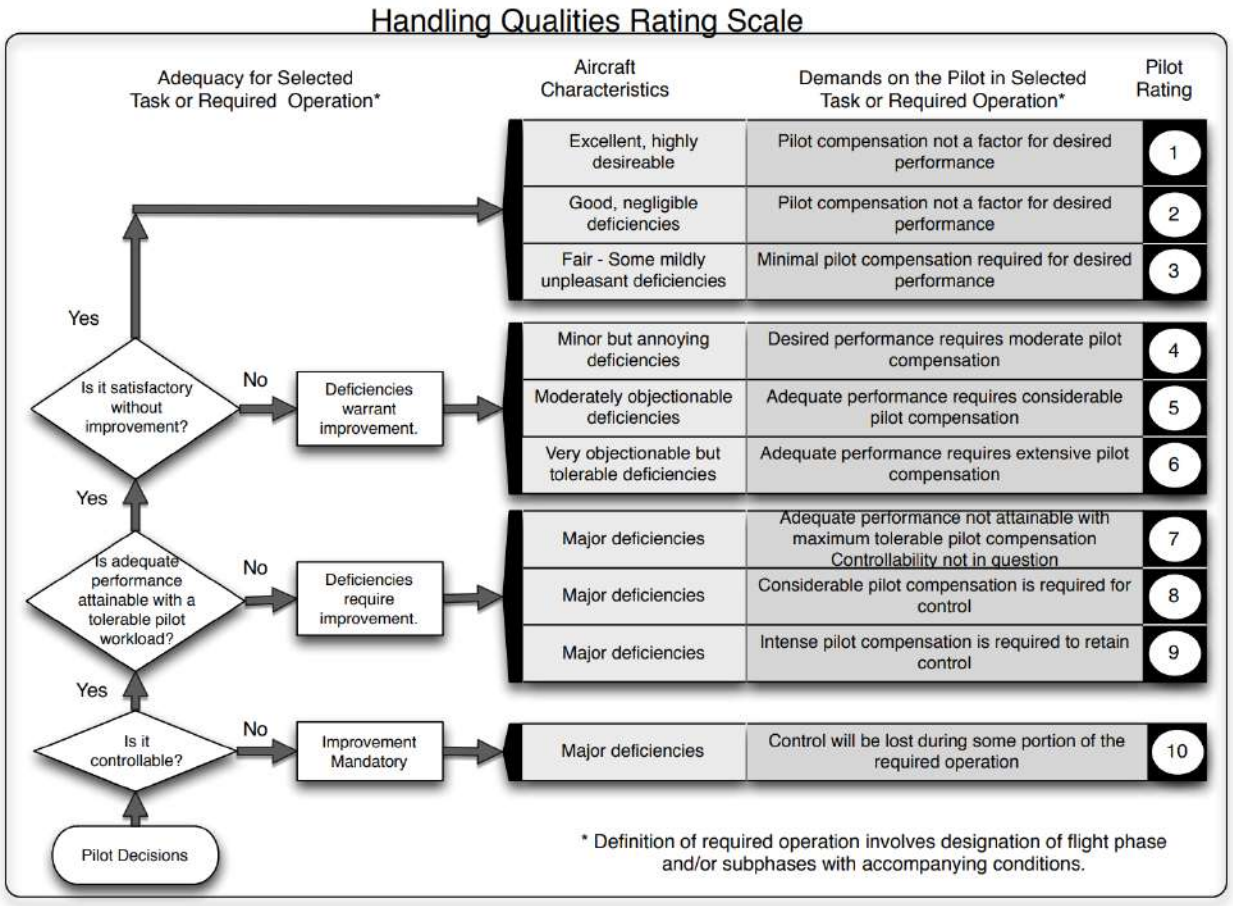


Figure 51: Cooper Harper HQ Rating Scale

E.8 PIO Rating Scale

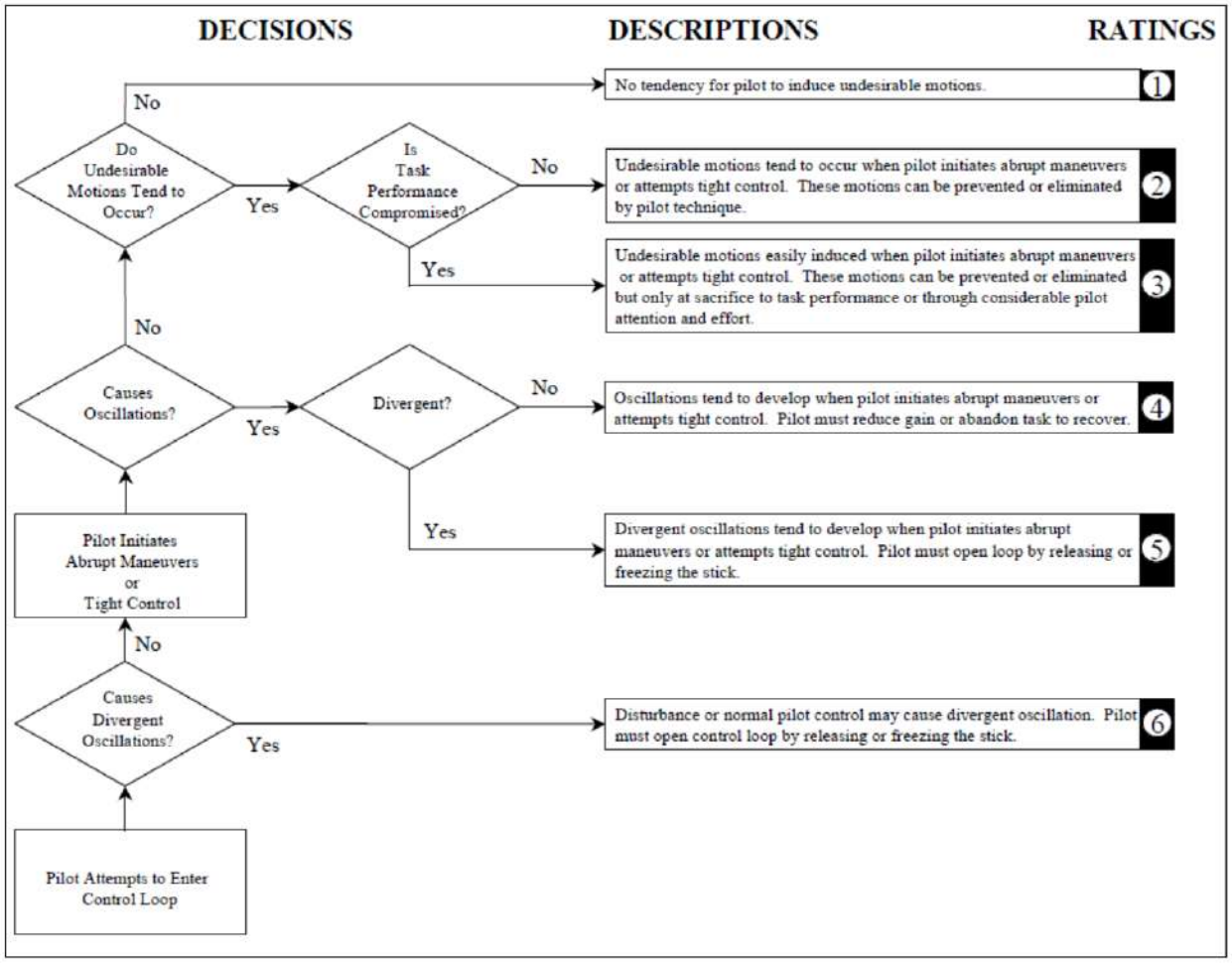


Figure 52: PIO Rating Scale

E.9 Bedford Workload Rating Scale

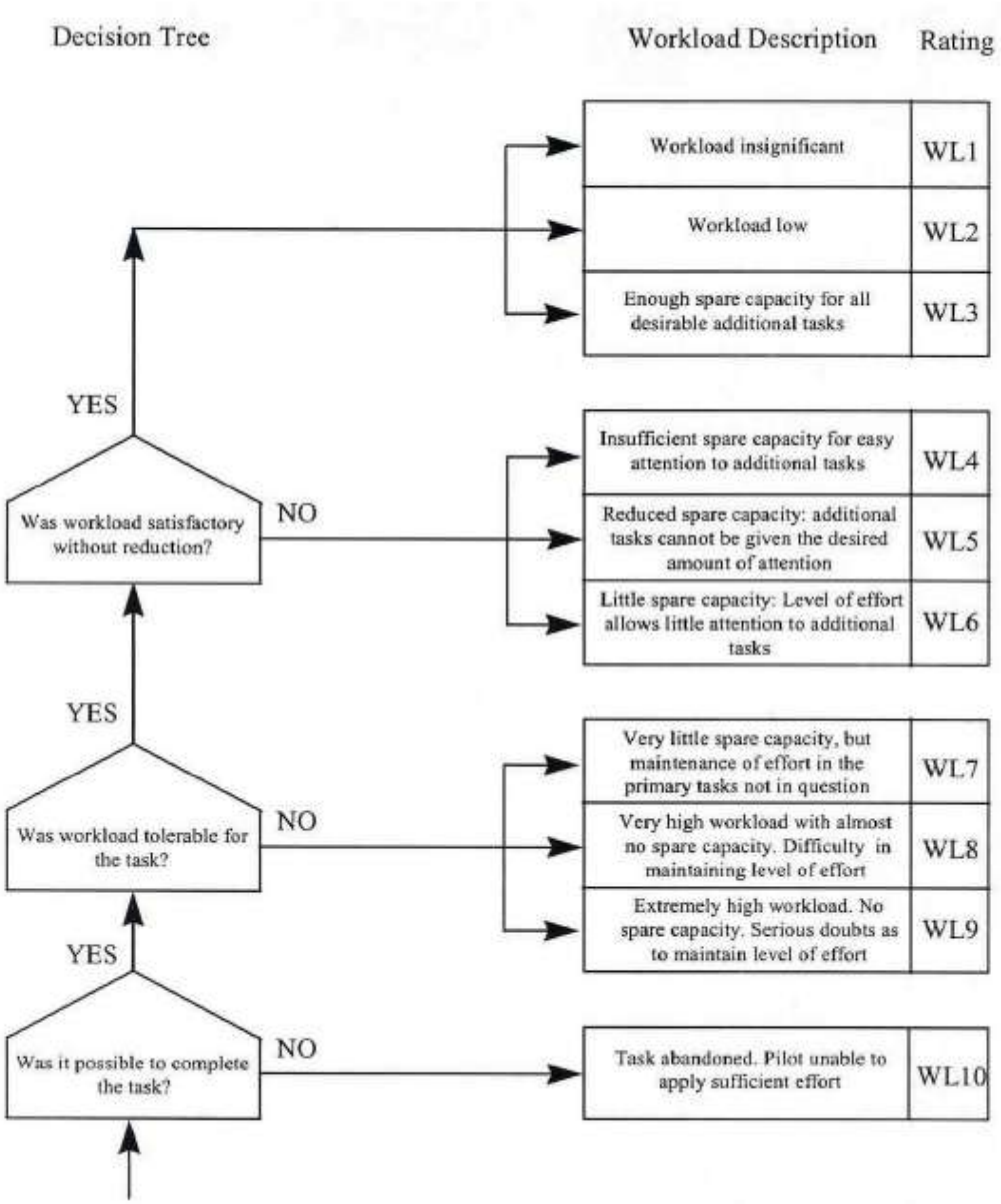


Figure 53: Bedford Workload Rating Scale

ANNEX F Instrumentation and Data Reduction

F.1 Exploited Instruments

Figure 54: Tape Measure

Figure 55: Stopwatch

Figure 56: Smartphone

Portable Flight Test Instrumentation (FTI): iLEVIL3-AW consists of an inertial reference unit, internal power source and a GPS antenna. It was used to collect inertial data such as aircraft angles and their rates, GPS position and groundspeed with a rate of 5 Hz. It was mounted aligned with the longitudinal axis of the aircraft behind the pilot's seat, in front of the acrylic glass that divides both cockpits.

Figure 57: iLevel Portable FTI

Figure 58: Action Camera

Flight Data Logging: The flight data logging feature of GARMIN G3X automatically stores basic flight parameters such as airspeed, altitude, aitch, bank, and engine data once per second (1Hz) to a secure digital card (SD card). A data file was created each time the system was powered on with as SD card inserted, or each time an SD card was inserted after power on.

Figure 59: Garmin G3X Flight Data Logging

F.2 Collected Data

TP#	Time (sec)	Vi (KIAS)	Altitude Deviation (ft)	OAT (°C)	Fuel (liters)	Thrust (%)
2.3	0	110	13000	-10	1105	103
	10	129	-40	-10	1102	103
	20	141	0	-10	1099	103
	30	158	0	-10	1097	103
	40	173	0	-10	1094	103
	50	189	0	-10	1091	103
	60	203	20	-10	1088	103
	70	217	-10	-10	1086	103
	80	228	-10	-10	1083	103
	90	240	-20	-10	1080	103
	100	250	0	-10	1077	103
	110	259	0	-10	1075	103
	120	267	0	-10	1072	103
	130	273	0	-10	1069	103
	140	281	0	-10	1066	103
	150	287	0	-10	1063	103
	160	291	0	-10	1061	103
	170	296	-20	-10	1058	103
	180	300	0	-10	1055	103
	190	303	10	-10	1052	103
	200	306	20	-10	1050	103
	210	309	0	-10	1047	103
	220	310	0	-10	1044	103

Table 37: Test Data of Level Acceleration

TP#	Vi (KIAS)	Nz (G)	Φ (°)	Altitude (ft)	Thrust (%RPM)	Stick Force (lbf)
2.4	302	1.45	45	13 020	103	3
	287	2	60	13 070	103	8
	253	2.5	67	13 040	103	15
	225	2.7	69	12 980	103	20
2.5	202	2.1	62	12 950	103	8
	180	2.0	60	13 040	103	8
	160	2.0	60	12 960	103	8
	142	1.9	60	12 880	103	8
2.6	252	5.0	80	13 800	103	15
	233	4.2	80	13 600	103	15
	210	3.8	70	13 500	103	12
	188	3.1	65	13 200	103	10
	172	3.0	65	12 800	103	8

Table 38: Test Data of Maneuver Performance

TP#	Test Description	Free play (%)	Centering	AFT Stick Force (lbf)	FWD Stick Force (lbf)
3.1 / 3.3	FCMC 140 / 200 KIAS	0	Absolute	1	1
		Free play (%)	Centering	Left Aileron Force (lbf)	Right Aileron Force (lbf)
		0	Absolute	1	1
		Free play (%)	Centering	Left Rudder Force (lbf)	Right Rudder Force (lbf)
		0	Absolute	2	2
		Target SPD (KIAS)	Fe (lbf)	Vi (KIAS)	Hpi (KIAS)
3.2	LSS 140	130	2	130	8280
		120	4	120	8420
		130	2	130	8240
		FRS	0	139	8080
		150	-3	150	7880
		160	-6	160	7740
		150	-4	150	8000
		FRS	0	139	8300
3.3	LSS 200	190	2	190	8260
		180	6	180	8420
		170	10	170	8720
		180	6	180	8640
		190	2	190	8440
		FRS	0	201	8160
		210	-3	210	7780
		220	-6	220	7440
		230	-15	230	7140
		220	-6	220	7100
		210	-3	210	7200
		FRS	0	202	7340

Table 39: Test Data of FCMC / LSS

TP#	Description	Half Cycle	Δ Time (sec)	Vi (KIAS)	Hpi (KIAS)
3.8	Phugoid 140 KIAS	1	0	120	8360
		2	22	139	8040
		3	48	126	8240
		4	69	138	8020
		5	90	128	8180
		6	113	137	8000
		7	133	129	8100
		8	155	136	7960
3.9	Phugoid 200 KIAS	1	0	170	8760
		2	32	231	7320
		3	63	180	8420
		4	90	233	7460
		5	123	189	8200
		6	153	217	7580
		7	181	195	8100
		8	214	213	7700

Table 40: Test Data of Phugoid

TP#	Description	Rudder (%)	Vi (KIAS)	Hpi (KIAS)	Fr (lbf)	Fa (lbf)	δr (%)	δa (%)	Bank (°)	β (°)
3.12, 3.14	WLSS / SHSS 140 KIAS	50 Left	141	8220	15	-4	50	15	-5	-3
		100 Left	142	8240	30	-7	100	20	-10	-6
		50 Right	141	8200	-10	4	-50	10	8	2
		100 Right	141	8260	-30	6	-100	15	8	5
Stick pitch force to pull: 4 lbf.										
3.13, 3.15	WLSS / SHSS 200 KIAS	50 Left	200	7440	30	-4	50	10	-10	-3
		100 Left	199	7360	50	-6	100	15	-15	-4
		50 Right	200	7320	-30	5	50	10	10	4
		100 Right	200	7300	-50	7	100	15	15	6
Stick pitch force to pull: 5 lbf.										

Table 41: Test Data of LDSS

TP#	Rudder %	Δ Time (sec)	Overshoot	Max Bank (°)	Max β (°)	Dominance
3.16	50 Fixed	6	5	10	3	Roll
	50 Free	6.5	5	10	3	
3.17	50 Fixed	6.2	6	10	3	Roll
	50 Free	6.46	6	10	3	


Dutch Roll iLevel Data.xlsx

Table 42: Test Data of Dutch Roll

TP#	Time %50 L2R (sec)	Time %50 R2L (sec)	Time %100 R2L (sec)	Time %100 L2R (sec)	%50 Fa (lbf)	%100 Fa (lbf)
3.18	2.7	2.5	1.29	1.3	4	10
3.19	2.3	2.18	1.12	1.28	4	10


Roll Rate iLevel Data.xlsx

Table 43: Test Data of Roll Performance

TP#	Nz (G)	Φ (°)	Vi (KIAS)	Fe (lbf)
3.10	1.5	45	139	2.5
	2.0	55	138	5
	2.5	65	139	7

Table 44: Test Data of LMS for 140 KIAS

TP#	Nz (G)	Φ (°)	Vi (KIAS)	Fe (lbf)
3.11	1.5	50	203	3
	2.0	55	203	10
	2.5	65	202	15
	3.0	70	202	18
	3.5	75	199	20

Table 45: Test Data of LMS for 200 KIAS

F.3 Data Reduction

F.3.1 AITOFF Plot

To be submitted as a separate folder (Annex F.3.1 AITOFF Plot).

F.3.2 Level Acceleration

Annex F.3.2 Level Acceleration.xlsx

F.3.3 Maneuver Performance

Annex F.3.3 Maneuver Performan

F.3.4 FCMC / LSS

Annex F.3.4 FCMC-LSS.xlsx

F.3.5 Phugoid

Annex F.3.5 Phugoid.xlsx

F.3.6 SHSS

Annex F.3.6 SHSS.xlsx

F.3.7 Dutch Roll

Annex F.3.7 Dutch Roll.xlsx

F.3.8 Roll Rate Time Constant

Annex F.3.8 Roll Rate Time Constant.xlsx

F.3.9 Roll Response

Annex F.3.9 Roll Response.xlsx

F.3.10 LMS

Annex F.3.10 LMS.xlsx