Aircraft control has progressed considerably since the early experiments of the Wright brothers in wing twisting. A diverse range of control schemes has since been developed to manage various aspects of the flight environment. A modern airliner, for instance, uses dozens of different control surfaces. Such highly specialized controls prohibit high performance throughout the wide flight envelope and offer little for redundancy. The concept of a morphing aircraft, however, would address these issues by allowing complete control of the aircraft structure for both primary control and multi-role situations. This research investigates a discretized approach to morphing the trailing edge of the wing. A UAV was modified to incorporate simple morphing capability and was flight tested extensively. The resulting system identification indicated that the lateral and longitudinal dynamics could be accurately modeled using simple linear-regression techniques. Both differential and collective deflection of the wing segments showed potential for full authority control over the aircraft. Using the models generated, controllers for the aircraft are being developed to fully exploit the potential of a highly configurable control system.

INTRODUCTION

The continuing maturation of technology is resulting in significant increases in performance for aircraft. Future designs must fully utilize these technologies to achieve mission objectives requiring a multi-role aircraft with high agility and low observability. Two approaches commonly envisioned for such designs are morphing aircraft and tailless aircraft.

An enabling technology to realize high performance aircraft is innovative control effectors. The benefits of this technology were extensively investigated for several types of effectors in the ICE project. These effectors were clearly shown to enable high levels of performance for the imagined tailless vehicle. For the ICE project, the effectors included rigid surfaces positioned in strategic locations to act as flaps, tips, elevons, and spoilers.

The concept of morphing the control surfaces provides an additional level of innovation that can increase the controllability. Obviously, the full benefit of morphing requires the entire aircraft to be altered. However, such a morphing is clearly beyond the range of current technology.

Instead, it is possible to realize limited morphing that is restricted to small components like control surfaces. True morphing of a control surface is not always practical, but approximations to the morphing can be easily implemented. In particular, limited shaping of the control surface is a simple form of morphing that is not overly difficult to achieve.

The University of Florida has recently initiated a project to study the use of a trailing-edge surface that may be shaped. The actual shaping is not true morphing; rather, the shaping is accomplished by separating each control surface into 8 segments. Each segment is independently positioned and allows for a type of discrete morphing shown in Figure 1.

Figure 1: University of Florida trailing-edge shaping testbed with 16 independent aileron segments
This paper presents the initial results of a project to characterize and control the flight dynamics of an unmanned aerial vehicle (UAV) with a segmented trailing-edge control surface. The preliminary phase of the project involves designing and implementing the aircraft to be a suitable platform for flight control. The project then considers modeling the flight dynamics by measuring flight data in response to control surface pulses and analyzing that data using system identification techniques.

**VEHICLE OVERVIEW**

The airplane used for this research is an FQM-117B radio controlled miniature aerial target as shown in Figure 2 and Figure 3. Several of these aircraft have been provided to the University of Florida by personnel at the Ft. Eustis Army Base. The model design is based roughly on the Russian MiG-27 Flogger. The aircraft were originally constructed to serve as target drones for Stinger missiles, but are easily modified for the project described in this paper. The modifications included addition of landing gear and rudder control.

The MiG-27 aircraft are operated using a small single-cylinder engine, a fixed-pitch propeller, and a radio control transmitter. The transmitter provides control over engine throttle, aileron, elevator, rudder, and four auxiliary channels. For this research, the throttle, elevator, and rudder controls are left unmodified. The aileron and auxiliary controls are used in conjunction with an on-board processor to control 16 aileron segments attached to the trailing edge of the wing. Such a configuration allows the control input to remain simple and easy to pilot while allowing control of multiple actuators.

The models are excellent platforms for flight research due to their ease of use and exceptional flight performance. The Styrofoam used for construction of the airframe facilitates modification for the trailing edge surface control. Furthermore, the size and payload capacity of the aircraft permits standard off-the-shelf components to be used for instrumentation and control. Table 1 lists the primary specifications of the aircraft.

![Figure 2: Overhead view of the MiG-27 flight testbed](image)

![Figure 3: Front and side views of the MiG-27](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
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</tr>
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<td>Wingspan</td>
<td>5.5 ft</td>
</tr>
<tr>
<td>Wing area</td>
<td>800 in²</td>
</tr>
<tr>
<td>Airspeed, takeoff</td>
<td>20 knots</td>
</tr>
<tr>
<td>Airspeed, cruise</td>
<td>50 knots</td>
</tr>
<tr>
<td>Empty weight</td>
<td>8 lbs</td>
</tr>
<tr>
<td>Maximum weight</td>
<td>13 lbs</td>
</tr>
</tbody>
</table>

Table 1: Specifications of the MiG-27 model

**CONTROL SURFACE SHAPING**

As used by the Army, the MiG-27 roll control system consists of two half-span ailerons hinged along the trailing edge of the wing. A single servo is normally used to actuate both surfaces. For the purposes of this research, these ailerons are replaced by 16 independently actuated control surfaces. Each of these are equally sized and evenly spaced along the trailing edge of the wing.
Each of the aileron-segments is connected to a servo-actuator embedded in the wing surface. While the total control surface area remains the same as on the original aircraft, the individual surfaces allow for increased configurability. These surfaces are configured to operate either collectively or differentially. Although each segment is controlled independently, various modes of operation are implemented to simplify open-loop flight testing.

The primary means of controlling the wing servos is using uniform differential control, where all the segments on the one wing panel deflect opposite to the segments on the opposing wing panel. Such control emulates the traditional means employed by the Army in the use of the MiGs. All 16 servos are actuated simultaneously as though conventional ailerons. This flight mode is used during takeoff, landing, and standard maneuvering. For testing aspects of the flight, it is also used for control pulses.

The individual-differential command mode enables discrete control of each set of trailing edge segments. Each segment is paired with the corresponding segment on the differential wing panel. During command input, these surfaces are deflected similarly to ailerons, where one surface undergoes positive deflection and the other undergoes negative deflection. Such a control mode is designed to primarily excite the lateral directional modes of the aircraft.

The individual-collective command also controls only two paired trailing edge segments at one time. However, the surfaces undergo identical deflection, where both surfaces deflect up or down at once. This deflection is similar in nature to flaps, which primarily affects longitudinal motion. A trailing edge profile of each control surface shape is illustrated in Figure 4.

**FLIGHT HARDWARE**

One of the challenges of multiple-actuator control concepts lies in the development of the control algorithm. Independent actuation of 16 wing servos in addition to the elevator, rudder, and engine throttle using existing equipment would have been time and cost prohibitive. Thus, both the hardware and software needed to control the servos were developed or assembled specifically for this research.

The core of the control system is a 16-MHz Atmel ATmega 128 microcontroller (MCU) shown in Figure 5. The primary purpose of the device is to simplify the task of operating the aircraft. The pilot cannot be expected to control 16 individual wing segments as well as the other aircraft controls. Rather, the pilot commands are used as inputs to the MCU which then controls the servo array directly. The control mode is programmed in software and can be changed between flights for different tests.
The pilot observes the airplane from the ground and commands throttle, aileron, elevator, and rudder control using a hand-held radio controlled transmitter. This device transmits a signal to the airborne receiver, which is mounted in the fuselage. The receiver then converts this signal into a pulse train, where the length of each pulse is proportional to the input command. This process repeats every 20ms, resulting in a control rate of 50Hz.

Pilot command is measured using the input capture pin of the MCU. This process measures the time length of each pulse and converts it into a scaled 8-bit integer, where 0 is the extreme negative deflection, 255 is the extreme positive deflection, and 127 is the neutral position. The MCU then operates on the command signals and computes the desired position for each servo based on the control algorithm used. The final step in the process is sending the computed servo positions to the left-wing and right-wing servo controllers. These devices interface to the MCU through a serial line and generate the pulse width modulation signals needed to the servos.

INSTRUMENTATION

The instrumentation on-board the MiG aircraft consists of angular rate gyro and accelerometers. Each of these is measured on three axes, resulting in six total measured aircraft states. Although this is short of a complete flight test instrumentation suite, it is sufficient for preliminary analyses of both lateral-directional and longitudinal dynamics.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
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</thead>
<tbody>
<tr>
<td>3-axis linear acceleration</td>
<td>(a_x, a_y, a_z)</td>
</tr>
<tr>
<td>Angular rates (roll, pitch, yaw)</td>
<td>(p, q, r)</td>
</tr>
<tr>
<td>Control surface deflection</td>
<td>(\delta_x, \delta_y, \delta_z)</td>
</tr>
</tbody>
</table>

* denotes \(i^{th}\) aileron segment, \(1 < i < 8\)

Table 2: Sensor measurements

A 3-axis rate gyro sensor board has been manufactured for use on the MiG. This board uses commercially available muRata rate gyro arranged orthogonally. The large measurable range, low-drift characteristics, and dynamic response of the gyro are appropriate for UAV flight testing.

The feedback potentiometers on the servos are used to generate control input data. While the primary purpose of these potentiometers is to provide internal feedback for the servo circuitry, it is also used as an external measure of servo position and resulting control surface deflection. Although some finite delay may exist between command input and servo motion, the speed of the servo and the self-aligning characteristics make such considerations negligible. Furthermore, measurement of the actual deflection as opposed to the commanded deflection results in an improved relation between control input and aircraft response.

The servos are modified to provide feedback data by removing the case and soldering leads to the ground and center-pin terminals of the feedback potentiometer. Both the physical connection and the high-impedance of the data acquisition channels prevent any interference with the normal operation of the servo.

A micro data acquisition system (µDAS) developed by NASA Langley Research Center is used to record and store the sensor output data (Figure 6). This device is a 7-gram board capable of recording 30 analog input channels at a 50-Hz sampling rate. The first three channels are occupied by a set of 3-axis accelerometers integral to the board. The remaining 27 channels are used to record external sensor data such as gyros and potentiometers.

![Figure 6: Micro data acquisition system](image)

The µDAS uses dataflash memory to record data during the flight test. The data is stored in non-volatile memory and is downloaded to a PC upon landing. This method is preferred to telemetered data because of the decreased occurrence of data loss. USB interface to the device allows 20 minutes of flight data to be downloaded in 6 minutes.

SAFETY/REDUNDANCY

Numerous precautions were taken in the hardware and software development to ensure some degree of redundancy in each of the flight systems. Although the use of a UAV involved considerably less risk than a manned airplane, the size and speed of the MiG model
warranted steps to decrease the possibility of loss of control. The most notable step taken was to flight test the model in a remote location. The open field area permitted effective testing of the aircraft without infringing on neighboring properties. Additionally, the testing was performed without any other aircraft, whether model or full-scale, operating in the vicinity.

For hardware redundancy, two receivers were used for control of the MiG. The primary receiver controlled engine throttle, elevator, and rudder, while the secondary receiver was used to interface with the MCU. Should the wing servos fail in some arbitrary deflection, the MiG would still be controllable.

The final precautionary measure was taken in the software development. Each unproven actuation mode was thoroughly tested in the lab prior to flight testing. The code used for the microcontroller was kept simple to minimize processing requirement and possibility of program failure. Furthermore, programming loop exit conditions were implemented to allow the MiG to return to conventional flight mode from any other type of actuation. Throughout an 8-month testing period that included numerous hardware, software, and instrumentation revisions, no major incident has occurred apart from the occasional rough landing.

**FLIGHT TESTING**

The model of the MiG has been undergoing extensive flight testing (Figure 7). Such flight tests are currently being conducted at the University of Florida in addition to the continuing projects at organizations such as NASA Langley Research Center and the Ft. Eustis Army Base. The full range of testing covers all aspects of modeling and control.

Open-loop flight testing is performed with the MiG –27 aircraft using procedures developed by NASA Dryden Flight Research Center. These procedures outline recommended instrumentation and maneuvers needed to characterize airplane dynamics. Specifically of interest in this case is the control pulse maneuver, which is used to determine the control effectiveness and stability and control derivatives. A control pulse is a maneuver where rapid control input is used to upset the aircraft from a stable trim condition into oscillatory motion. This input is typically in the form of a doublet, where the control surface is quickly actuated in both directions. The response of the aircraft to such inputs is used to identify frequency and damping of the oscillatory motion, in addition to parameter identification.

Seven sets of control pulses are performed using different configurations:

1. Conventional one-piece aileron
2. 16 simultaneously-deflected aileron segments
3. Conventional elevator surface
4. Conventional rudder surface
5. Independent-differential deflection of two aileron segments
6. Independent-collective aileron segments
7. Simultaneous-collective aileron segments

Sets 1 and 2 are used to determine the unmodified behavior of the aircraft. The lateral-directional stability and control derivatives obtained from this testing and subsequent analysis establish a baseline for comparing with the modified aircraft. These two sets differ only by control surface power to size ratio. Geometrically, however, the two are identical and expected to produce similar results.

Sets 3 and 4, using conventional control surfaces, are flown for completeness of the aircraft model. These tests are not affected by the 16 wing servos, although they do help in the understanding of the overall aircraft dynamics.

Sets 5, 6, and 7 involve an individual segment approach to flight testing. Each pair is tested individually to determine the contribution to the overall system dynamics. In this manner, the localized effect of the trailing edge shaping can be determined and related to the other segments in effectiveness. The data and resulting models from these tests will be beneficial in developing future controllers that will optimally control the aircraft to minimize some objective function.
The primary maneuver used throughout the flight testing is the control pulse. The control pulse maneuver evaluates the aircraft perturbations about a trim condition. This effectively isolates the effect of the control surface deflection on the aircraft response. Several different control pulses are used for each set. Doublets, for instance, are maneuvers where the control surface is deflected in one direction for a short period, then in the differential direction, and finally to neutral position. The aircraft is then allowed to oscillate freely and recover from the maneuver. 3-2-1-1 pulses are slightly more complex inputs, where the control surface is commanded to one side for three time periods, then to the differential side for two time periods, and finally a one-time period pulse in each direction. Historically, this has been shown to produce the most favorable aircraft response for identifying dynamic behavior.

The flight test procedure includes preflight preparation, takeoff/setup, flight test maneuvers, and landing/data recovery. In the preflight stage, the aircraft is checked for proper weight and balance. The installed hardware is also checked for security and correct operation. Additionally, the instrumentation and data acquisition system are initialized and begin recording sensor data. Once the pilot reviews the required maneuvers for the flight, a brief control check is made by deflecting each surface to the maximum and minimum position. Aside from ensuring correct control movement, this also generates a record of these motions in the data. This has proven to be useful in the data analysis.

With the preflight check complete, the takeoff is initiated by applying full engine power and accelerating the MiG down a grass runway (Figure 8). Once suitable airspeed is attained, the pilot initiates a climb to 500 feet altitude. Maneuvers at this height remain observable, yet are high enough to facilitate recovery from upset attitudes. The MiG is then trimmed for level flight.

Each flight maneuver begins with the aircraft in trimmed, level flight. A control pulse is then performed, which generally results in a small perturbation of the flight path. Following the command input for the maneuver, the controls are returned to neutral during ensuing aircraft response. A recovery from the maneuver is initiated a few seconds later. At the conclusion of each maneuver, the pilot turns the aircraft 180° and re-establishes trim for the next control pulse. Each maneuver of interest is performed numerous times to generate sufficient data.

For both longitudinal (elevator) and lateral-directional (aileron, rudder) pulses, the inputs are generally small and have short durations. This is to try and retain the aircraft in a regime that can be adequately represented using a linear model. Large maneuvers tend to involve non-linearities that would make model identification difficult. As such, the maneuvers presented in this paper are benign motions that can be described as slight perturbations about trim. This type of maneuver has the added benefit that other factors affecting the flight dynamics such as angle of attack, sideslip angle, and airspeed incur little change and are assumed constant.

On completion of the flight testing, the pilot stops data recording and begins a descent in preparation for landing. The MiG lands on the same grass runway used for takeoff under pilot command. The flight data is then downloaded to a laptop for analysis.

SYSTEM IDENTIFICATION
MODELING

The flight data from the tests was analyzed to formulate models of the flight dynamics. Such models are essential to properly analyze the flight dynamics and synthesize controllers. Also, these models are particularly important to quantitatively characterize the control authority provided by the segmented trailing-edge control surfaces.

The models are formulated using an optimization approach. Specifically, coefficients are determined to minimize the difference between the flight data and an auto-regression model with external inputs (ARX)\(^5\). This ARX model, which is formulated as a discrete-time difference equation, is then alternatively expressed as a state-space representation. Finally, the discrete-time state-space model is converted to a continuous-time state-space model using a Tustin transformation\(^1\).

The resulting models are linear and describe the linearized dynamics of the aircraft. The assumption of linearity is especially convenient because it allows the
longitudinal and lateral-directional dynamics to be considered decoupled. As such, the system identification for the longitudinal dynamics can consider the collective trailing-edge surfaces and elevator while the lateral-directional dynamics can consider the differential trailing-edge surfaces and rudder.

LATERAL DIRECTIONAL DYNAMICS

A model of the lateral-directional dynamics is identified by analyzing measured responses to the differential trailing-edge surfaces and rudder. This model has 10 inputs and 2 outputs. The inputs to the model are the original aileron, segments from outboard to inboard, and rudder. The outputs of this model are roll rate and yaw rate. The state-space representation of the model is given as $P$

$$P = \begin{bmatrix} A & B \\ C & D \end{bmatrix}$$

$$A = \begin{bmatrix} -0.450 & 0 & 0 & 0 \\ 0 & -4.590 & 0 & 0 \\ 0 & 0 & -2.228 & -12.076 \\ 0 & 0 & 12.076 & -2.228 \end{bmatrix}$$

$$B = \begin{bmatrix} 0.414 & -1.949 & 1.441 & 1.268 \\ -0.067 & -0.178 & 0.021 & 0.166 \\ -0.079 & -0.208 & 0.025 & 0.195 \\ -0.085 & -0.246 & 0.029 & 0.231 \\ -0.083 & -0.193 & 0.023 & 0.180 \\ -0.830 & -0.204 & 0.024 & 0.191 \\ -0.069 & -0.171 & 0.020 & 0.160 \\ -0.049 & -0.109 & 0.013 & 0.102 \\ -0.099 & -0.138 & 0.033 & 0.206 \end{bmatrix}$$

$$C = \begin{bmatrix} 0.074 & -1.624 & -1.234 & -1.451 \\ 0.379 & -0.233 & 0.176 & -0.146 \end{bmatrix}$$

$$D = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

The modal parameters of this model are obviously of interest as descriptors of the flight dynamics. The model is estimated as having 4 states whose poles correspond to 2 convergences and an oscillatory mode. Table 3 gives the frequency and dampings of these modes.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Frequency</th>
<th>Damping</th>
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</thead>
<tbody>
<tr>
<td>Roll</td>
<td>0.7433</td>
<td></td>
</tr>
<tr>
<td>Spiral</td>
<td>0.0654</td>
<td></td>
</tr>
<tr>
<td>Dutch roll</td>
<td>2.2636</td>
<td>0.1868</td>
</tr>
</tbody>
</table>

Table 3: Lateral Directional Dynamics

An evaluation of the model is performed by comparing responses measured by the actual aircraft to responses simulated by the model. The responses to different surfaces are separated for ease of presentation.

Consider the responses to aileron commands shown in Figure 9. These responses relate the flight dynamics to the original aileron that is not segmented. The simulated values of roll rate and quite similar to the measured values in both magnitude and frequency. The responses of the yaw rate are not quite as correlated between the simulation and flight test but the general trend is clearly captured by the model.

The lateral-directional model correctly shows lower frequency trends that are clearly a result of control input, while ignoring higher frequency data that is likely attributed to noise.

Control pulse data from individual aileron segment pairs are shown in figures 10 and 11. The data and model are in close agreement for both roll and yaw rate. Curiously the roll rate generated during most of the segment pulses was very similar. Previous predictions of linearly increasing roll rate with increasing moment arm proved unsubstantiated. This is perhaps due to the tapered wing planform of the MiG. A decrease in the roll rate occurred with the 3 innermost segment pairs.
The expanded plots of figure 11 show the flight data from the outboard segments in greater detail. The roll characteristics of this segment pair closely match that of the rudder.

Figure 11: Actual and simulated response to outboard aileron segment control pulses

Figure 12 shows a similar set of plots for a series of rudder doublets. The correspondence between measured and simulated roll rates is good. The yaw rate, however, is not quite as close an approximation. Nevertheless, the plots show that the MiG-27 lateral-directional dynamics can be approximated by a linear flight model to a reasonable degree of accuracy.

Figure 12: Actual and simulated response to rudder control pulses

The flight data from the tests contained 10 inputs (aileron, rudder, and 8 surface pairs) and 6 inputs (acceleration and angular rates). A transfer function was computed between each input and roll rate. These functions are used to generate the frequency response plots shown in Figure 13. The very close correspondence of superpositioned with the conventional aileron control indicates that the summation of the individual aileron segment roll contributions is equal to the total roll dynamics. This suggests that the dynamics can be treated in a piecewise manner, where each segment has a known, fractional contribution to the overall system dynamics.

Figure 13: Frequency response of roll command aileron (—), individual segments (…), superpositioned total of segments (---)
LONGITUDINAL DYNAMICS

Additional flight tests of the MiG-27 were performed to identify the longitudinal dynamics. Control pulses to both the elevator and individual-collective segments were flown using the same testing procedure used for the lateral-dynamics analysis.

Initially, these tests were designed to quantify the short-period mode and possibly phugoid mode through a series of elevator pulses. Throttle settings were held constant throughout the entire series of control surface pulses. Successive flight tests of collective aileron segment actuation were then flown and compared to the aircraft responses from elevator pulses.

As with the aileron and rudder control pulse maneuvers, the elevator pulses began with the aircraft in trimmed, non-accelerating level flight. The elevator was then deflected upwards for one second, downwards for one second, and up for one second. At this point, the controls were released and the airplane was allowed to freely oscillate and recover. The flight data from two elevator pulses (Figure 13) shows the commanded deflection, pitch rate response, and vertical acceleration response. The resulting flight path resembled a sinusoidal wave as the aircraft climbed, dove, and returned to level flight.

A linear model of the longitudinal control shows a close correspondence with the flight data. For both the pitch rate plot and vertical acceleration plot of Figure 14, the simulated response shown in the solid line accurately models the aircraft response throughout the maneuver.

A short period mode was identified from the model at 11.46 Hz. However, the short duration of the maneuver precluded identification of the phugoid mode. This mode is typically very low frequency and requires a long maneuver to accurately determine. Such a maneuver is excessively difficult with a remotely piloted vehicle due to limitations in aircraft visibility and useful airspace. Flying the aircraft too far away from the pilot would make precision maneuvers unfeasible to perform, in addition to risking loss of aircraft control.

Further flight tests of the MiG’s longitudinal dynamics are flown using collective deflection of the trailing edge segments. Such deflection generally does not have an effect on lateral direction dynamics, but can have a significant effect on longitudinal trim and control. A basic form of such control is the conventional wing flap, which deflects or extends to change the lifting and moment characteristics of the wing. Such a change upsets the longitudinal trim condition and causes a pitch up or pitch down response.

Flight tests of the collective trailing edge deflection were flown immediately following elevator control pulses. This ensures that factors such as loading configuration, fuel level, and trim condition are close to uniform for both scenarios. However, unlike the elevator, rudder, and differential-aileron control pulses, the collective-aileron pulses were only flown using a single pulse magnitude. Response from single surface deflection was relatively small, requiring maximum deflection to generate a pitch rate above the signal noise level.

Figure 15 shows the control input and aircraft response to collective deflection of the trailing edge. The alternating dotted-solid lines in the upper plot represent actuation to different segments or control surfaces. The first dotted line series of pulses shows the elevator input. The resulting response, both in pitch rate and vertical acceleration, is relatively large even for such a small input. The following 8 series represent collective deflection of the extreme outboard two segments (#0 & #15) to the extreme inboard segments (#7 & #8). The final set of pulses corresponds to the uniform deflection of all 16 surfaces. Curiously, this input generates a response that is similar to the elevator input. In fact, the aircraft was observed in flight rapidly changing pitch angle during the maneuver. Early attempts at a control pulse were too long, causing a gross deviation in the flight path as the aircraft pitched up and approached stall.

The longitudinal model of the aircraft, shown in solid lines on the bottom two plots, corresponds well with the flight data. Although the measured flight data is noisy, the model clearly follows the response for all 10 pulse
types shown. As with the lateral-directional model, this indicates that the MiG-27 aerodynamic response is well approximated using a linear model. Such agreement bodes well for controller development, where linear assumptions can considerably simplify control design strategies.

Figure 15: Actual and simulated response to collective-segment control pulses

An expanded plot of control pulses to two segment pairs is shown in Figure 16. The actuation of the segments is controlled by a three-position switch on the transmitter. The resulting pulses are slightly improved over the aileron, elevator, and rudder pulses, which are controlled by a proportional stick. The step input afforded by the switch eliminates most of the pilot error and inconsistency seen in previous control pulse sets.

The aircraft response to these longitudinal segment pair pulses is considerably smaller than the response from other control surfaces. The large tail volume of the MiG contributes to high stabilizing forces, which would resist any moment generated by the wing segments. Nevertheless, both positive and negative actuation produced a measurable pitch rate. The center and lower plot of Figure 16 show what is most likely a steady state response to control inputs. A low signal to noise ratio for these maneuvers creates difficulty in assessing any modal dynamics. As a result, the model was considered to have a direct correlation between control input and pitch/acceleration response. The expected short period mode for this type of longitudinal control was not identified.

Figure 16: Collective control pulses to servo pairs 1 & 14 (…) and 2 & 13 (—). Expanded scale shows detail of input and response

Comparison

Figure 17 shows a comparison of the dutch roll frequency of the MiG-27 with five other aircraft. The plot shows the identified dynamics are in agreement with the trend seen in dutch roll frequency dependence on wingspan. Equation 6 shows the approximation for the dutch roll natural frequency. From this equation, all of the derivatives have a direct dependence on wingspan. Thus, the results seen in figure 15 appear reasonable.

$$\omega_n, DR = \sqrt{\frac{-\beta N_Y - \nu N_Y + u_0 N_n}{u_0}}$$  (6)

Figure 17: Dutch roll frequency vs. wingspan for 6 aircraft
CONCLUSION

The results of the flight testing show promise in the use of a UAV for preliminary morphing platform. Using basic techniques in construction, hardware development, and programming a segmented trailing-edge surface concept was developed and tested. Analysis of the data yielded the expected lateral-directional and longitudinal modes in line with similar vehicles. Furthermore, the segmented trailing-edge surface was shown to have a significant effect on the flight dynamics. Modeling such an effector as a series of discrete, superimposed linear models was adequate in representing the overall flight dynamics.

ACKNOWLEDGMENTS

The authors would like to acknowledge the important contributions made to this project. Mike French of the Ft. Eustis Army Base generously provided several aircraft models for use in this research. Mark Motter of the NASA Langley Research Center shared his experience and expertise with operating similar aircraft. The micro data acquisition system used to record flight data was developed and provided by Martin Waszak also of NASA Langley Research Center. Jason Grzywna, Jason Plew, and Joe Pippin provided significant hardware and expertise in developing the MiG control system.

REFERENCES


