

NGFMS GOLD OPTION FOR EMBRAER E-JET

Delivering fuel savings quantified using
Honeywell Forge Flight Efficiency

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INTRODUCTION

The Gold package option for the NGFMS in Load 27.1 for the Embraer E-Jets, E170/175/190 and 195 adds several airline-specific capabilities to the Basic NGFMS that deliver quantifiable and measurable value to airlines operating these aircraft. The purpose of this paper is to review those functionalities and detail the value that they can provide operators.

The Gold Option contains two features that can provide quantifiable reductions in fuel burn for typical revenue service operations with the E-Jet. Those features are:

- Cost Index and ECON speeds
- Optimum (Off-idle) descent path creation and management capability; includes CDA*

The purpose of this paper is to provide a more in-depth understanding of these features of the Gold option package along with how these features can potentially create value for operators by reducing fuel burn.



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NGFMS AIRCRAFT PERFORMANCE MODEL

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One of the biggest advancements of the NGFMS is the design of the aircraft performance model.

The NGFMS aircraft performance model design is the culmination of over thirty years of design experience gained with Honeywell air transport aircraft FMS which was first certified as standard equipment on the Boeing 757/767 in 1984, and virtually every airline transport aircraft that has certified since. NGFMS has now been certified for the Embraer E-Jets, E170/175/190 and 195.

In general, the NGFMS performance function utilizes the current aircraft state and projects a simulated aircraft model through a modeled atmosphere along the flight plan through all flight phases: climb, cruise and descent in order to accurately predict time of arrival, fuel usage as well as other parameters. The performance function must provide accurate predictions through a variety of normal aircraft configurations (e.g., landing gear and flaps extended and retracted, bleeds on and off, etc.) as well as non-normal configurations such as engine out. Figure 1 provides a basic block diagram that generally describes the NGFMS Performance Design. The NGFMS performance design encompasses several key functions necessary for producing real time situational information as well as predictive data for the trajectory of the aircraft. The performance design also yields recommended optimal information essential for fuel savings.

THE NGFMS PERFORMANCE DESIGN ENCOMPASSES SEVERAL KEY FUNCTIONS NECESSARY FOR PRODUCING REAL TIME CURRENT SITUATIONAL INFORMATION AS WELL AS PREDICTIVE DATA FOR THE TRAJECTORY OF THE AIRCRAFT.



The performance design uses a numeric integration along the flight plan using the aircraft equations of motion. This integration yields highly accurate predictions of altitude, distance, weight, speed and time using Embraer-provided aero/engine tables based on first-principles of aerodynamics. Speed and thrust modes, as well as aircraft configuration are considered in these predictions to enhance accuracy. The accuracy of the predictions is core to the block in figure 1 named Flight Optimizations. It is through this block that the optimizations that are the topic of this paper and the sources of value provided by the Gold options package are achieved. For example, the FMS produces optimal speed targets based on aircraft performance characteristics and cost data via the cost index, the so-called Economy (or ECON speed).

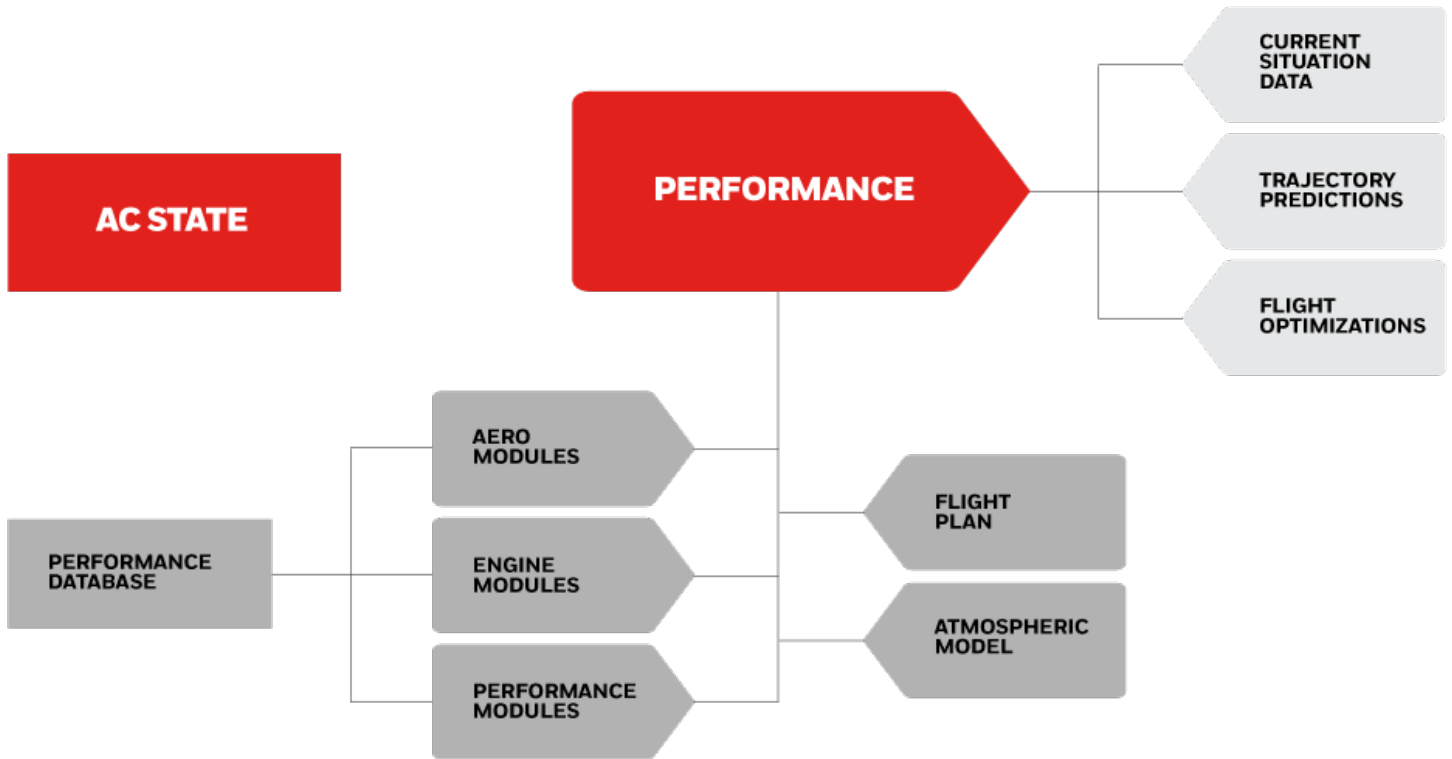


Figure 1: NG FMS Performance Design Block Diagram

COST INDEX, ECON SPEED AND ITS ROLE IN FUEL CONSERVATION

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A typical airline operator in general chooses to optimize its operation around one of several high-level objectives, all of which have implications on the selection of a speed to fly.

For example, minimize total trip time, minimize trip fuel or minimize total operating cost for the trip. The last objective, minimizing total operating cost for the trip, is specifically where Cost Index and ECON speed calculation and speed management by the FMS come into play.

Cost Index (CI) and ECON speeds are available only with the Gold package of NGFMS, so these functions are foundational to the underlying value of this option.

Cost Index (CI) is the ratio of time-related cost of the airplane operation not including fuel cost, to the cost of fuel. The CI then reflects the relative effects of fuel cost on overall trip cost as compared to time-related direct operating costs that are variable and incurred per hour of aircraft operation. In equation form:

$$CI = \frac{\text{Time - related costs \$}}{\text{Fuel Costs \$}}$$

The numerator of the CI is often referred to as time-related direct operating cost not including cost of fuel. Components of variable operating costs can include items such as crew wages, engines or auxiliary power units and even entire aircraft when they are leased by the hour. Similarly maintenance costs can be accounted for on airplanes relative to the hours the aircraft is actually flown.

For a particular airline, the numerator is reflective of the airline's cost structure and may vary from one aircraft type to another within their fleet. If the majority of the operating costs for a particular aircraft are fixed and not tied to flying hours, the time-related direct operating costs in the numerator and the resultant CI are low because the airline is primarily trying to minimize the fuel cost for that aircraft. In other words, fuel cost is dominant in the total operational cost of that aircraft for that airline. Conversely if the time-related direct operating costs are high due to programs such as "power by the hour" and other programs such as Maintenance Service Agreements that result in incurring costs per flight hour. The numerator and CI are higher as the airline is trying to minimize time flown, using higher speeds and burning more fuel as fuel costs are not dominant in their cost structure.

THE NGFMS PERFORMANCE DESIGN ENCOMPASSES SEVERAL KEY FUNCTIONS NECESSARY FOR PRODUCING REAL TIME CURRENT SITUATIONAL INFORMATION AS WELL AS PREDICTIVE DATA FOR THE TRAJECTORY OF THE AIRCRAFT.

The denominator in the CI formula may seem straightforward at first, but given the current environment with high variation in fuel prices, fuel tankering and fuel hedging strategies, it too can be rather complex and not uniform across all aircraft in a given airline's fleet. For the E-Jet aircraft in particular which is operated by regional carriers as contractors to a major airline, fuel may be provided by the mainline carrier and has no direct costs for the E-Jet operator. This is an example where a higher Cost Index could be used to minimize trip time and hours flown on each airplane, especially if the operator has relatively high time-related direct operating costs.

The key in this discussion of value is that the CI and ECON speeds included with the Gold package enable an airline to implement tactics at the individual flight level to achieve a selected cost control strategy, depending on the aircraft and airline specific operational parameters and cost structure (e.g., high or low time-related direct operating costs, dominance of fuel costs, etc.) Cost Indices can be used very tactically to recover schedule in the air when warranted for some flights or to minimize fuel burn when the airline is on schedule. Combined with the FMS-managed speeds in all flight phases that is part of the NGFMS Basic, the Gold Option and the use of Cost Indexing and FMS-calculated and managed speeds can be employed to deliver verifiable reductions of trip fuel in many common mission scenarios of between one and two percent. For airlines that currently have a cost indexing program in place, implementation of the program on the E-Jet with NGFMS and Gold is straightforward and requires minimal training. With Gold enabled, and a cost index value entered during performance initialization, the default FMS managed speed will be ECON in climb, cruise and descent.

FMS produces optimal speed targets based on aircraft performance characteristics and cost data via the cost index, the so-called Economy (or ECON speed).



Through the calculation of a single parameter, the Cost Index, the airline operations group can provide flight crews with an input to the FMS that enables it to calculate and control to a climb, cruise and descent speed schedule to match the operation of each aircraft, on each mission, to the desired cost optimization strategy. Moreover, if conditions change in the course of flight, a different cost index can be entered to realign the trip cost to constantly changing conditions such as known delays in the terminal area or the need to make up schedule due to departure delays.

With the NGFMS Gold Package it is possible for the flight crew to enter a Cost Index value in the FMS from 0 to 999, generally entering the value specified by the flight operations group which calculates the CI and sets the strategic optimization for each mission in terms of a fuel usage objective. Entering 'zero' for the CI results in an ECON airspeed calculation and selection that achieves maximum range and minimum trip fuel. Essentially the ECON speed calculation ignores the time-related direct operating costs. Conversely, entry of a CI of '999', the resulting ECON speed reflects a minimum time optimization—the speed schedule will call for maximum flight envelope speeds and effectively ignores the cost of fuel. In practice, these minimum and maximum CI values are rarely used. The airline will calculate and communicate a CI for each mission that is consistent with the high-level cost control strategy the airline is currently pursuing with the E-Jet fleet.

What is the next best alternative to Gold which enables the use of CI and determination of ECON speed? Without the Gold option, the FMS is limited to the calculation of Long Range Cruise (LRC) speed only. LRC speed is interrelated to Maximum Range Cruise (MRC). MRC is the speed that will provide the furthest distance traveled for a given amount of fuel burned and minimum fuel burned for a given cruise distance. LRC is defined as the speed in excess of MRC that will result in a 1% decrease in fuel mileage in terms of nautical miles traveled per pound of fuel burned. The advantage gained by LRC is through the trade of 1% of range, cruise velocity can be increased by 3-5% which of course reduces trip times. The LRC speed is almost universally higher than the ECON speed that will result from using a CI calculated using the airlines time-related direct operating costs and fuel costs that are specific to the airplane.

Another important benefit to flying ECON speeds based on the CI with Gold i stems from the inclusion of the Atmospheric Model in the NGFMS Aircraft Performance Model. The ECON speed calculation fully takes into account forecast winds at four flight levels that are entered into the flight plan at each waypoint during performance initialization. Winds and temperatures can be uploaded via AOC datalink to provide completeness of the environmental model without additional data entry by the crew. The ECON speed is optimized for wind conditions along the route of flight. For example, in the presence of a strong tailwind component on a given leg, the FMS ECON speed will be reduced in order to take full advantage of the increase in groundspeed due to the tailwind. Conversely ECON speed would be increased in the presence of a strong headwind to minimize the time penalty in order to maintain the top-level objective of the entered Cost Index.

THE COST INDEX FUNCTION INCLUDED IN GOLD ENABLES AIRLINES TO IMPLEMENT THEIR CHOSEN COST CONTROL STRATEGY AT THE AIRCRAFT AND MISSION LEVEL, OPTIMIZING OPERATIONS FOR MINIMIZING TIME-RELATED VARIABLE COSTS OR COST OF FUEL.

OFF-IDLE OPTIMAL PROFILE DESCENT

3

NGFMS constructs a flyable, near-flight idle descent path (often called 'off idle') that is used by the VNAV function to descend the aircraft efficiently on arrival from Top of Descent (T/D).

The off-idle descent path constructed corresponds to a near flight idle path that is built assuming an additional 40kt tailwind regardless of entered/actual wind conditions. This allows the Auto Throttle to manage speed through minor adjustments in the thrust level during the descent and providing margin that can be utilized if significant unplanned tailwinds or headwinds are present. The result is a shallower descent path (Flight Path Angle) than traditional idle descent, with an earlier Top of Descent where the aircraft reduces thrust and starts down the calculated descent path.

The NGFMS constructs a constant descent path consisting of geometric segments, fixed flight path angle (FPA) segments and off-idle segments. Geometric segments produce point-to-point segments which comply with the altitude constraints specified by the flight plan. Point to point paths provide a smoother ride during the constrained portion of descent (which often occurs while the cabin is being cleaned up) by eliminating the pitch-thrust coupling that is associated with throttle adjustments during descent to lower altitude and final approach.

THE OPTIMUM DESCENT PROFILE ALSO AUTOMATICALLY DETERMINES WHEN TO SLOW DOWN FOR SPEED RESTRICTIONS (SUCH AS 250KTS BELOW 10,000') AND MAINTAINS THE OPTIMAL CONSTANT DESCENT.

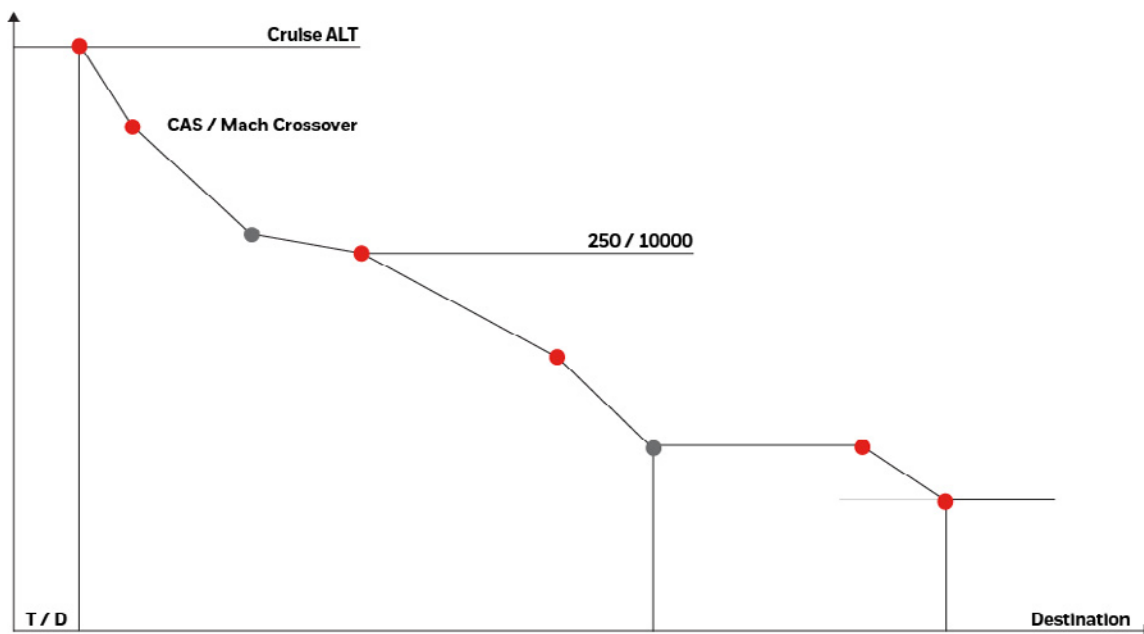


Figure 2: NGFMS Descent Path Construction

Above the last confining altitude constraint, a near idle path is constructed back to the final cruise altitude to define the descent path. The system constructs a descent path that avoids level segments during the arrival which can be particularly costly in terms of fuel economy at lower altitudes and in the landing configuration. The constant descent approach also reduces the noise footprint during arrivals since the aircraft stays higher longer. The optimum descent profile also automatically determines when to slow down for speed restrictions (such as 250kts below 10,000') and maintains the optimal constant descent.

Intuition would suggest that having the throttles at idle throughout descent would result in lower fuel burn in descent. However there is a "tipping point" where the increased time at cruise thrust to achieve the later ToD and higher Flight Path Angle necessary for a true idle descent actually negates the idle throttle setting during the descent with no tailwind component included in the calculation. In addition, in practice it has been found that maintaining idle thrust can prove problematic particularly with significant unplanned tailwinds or headwinds during the descent which would require the use of speed brakes or additional thrust in order to maintain airspeed both of which increase fuel burn in the descent segment.

Many studies have been performed on the off-idle descent and Continuous Descent Approaches and their impact on fuel efficiency. Those studies universally conclude that an off-idle descent can save significant fuel during approach in a steady, unconstrained descent versus other techniques that don't result in a continuous descent, or those that use a true idle descent. Their conclusions from the data were that the majority of the savings come from the earlier Top of Descent, and shorter duration of cruise thrust. Additional savings, they concluded, were provided by the ability of the auto throttle to fly at consistent descent speed, avoiding the use of speed brakes or additional thrust which again is provided by the assumption of the 40-knot tailwind component.

Note the qualifiers in the paragraph above: Steady, unconstrained descents from cruise altitude are not possible in all cases. When considering the fuel savings benefit of this feature of the Gold option, it should be calculated considering current and future arrival operations where the aircraft will be allowed by ATC to continue in cruise to the FMS-calculated TOD. That combined with operational measures an operator may have in place requires that the savings projection be customized to their operating environment and operational procedures.

Continuous Descent Approach (CDA)/Optimized Profile Descent are a key part of the airspace modernization efforts, and the ability to fully utilize this capability is expected to increase as initiatives such as SESAR and NextGen are implemented. In addition to fuel savings, CDA combined with RNAV RNP arrivals can provide significant reductions of noise, and contain the noise repeatably to areas that are least sensitive. Adding this capability to the E-Jet is consistent with preparation of the aircraft for fully compliant operations in the post-modernization airspace worldwide.

THE NGFMS CONSTRUCTS A CONSTANT DESCENT PATH CONSISTING OF GEOMETRIC SEGMENTS, FIXED FLIGHT PATH ANGLE (FPA) SEGMENTS AND OFF-IDLE SEGMENTS.

QUANTIFYING THE BENEFITS USING HONEYWELL FORGE FLIGHT EFFICIENCY

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The Honeywell Forge for Airlines platform is a nose-to-tail analytics solution that captures critical data from your aircraft network and delivers it directly to key members of your organization.

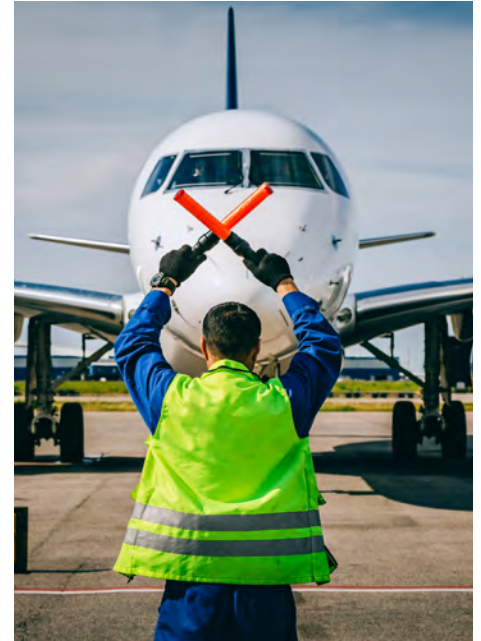
This real-time information enables your team to act quickly to enhance the well-being of passengers and maximize profits for your airline. Honeywell Forge is an analytics platform that enables you to store, access, manage, and serve events and policies that root out waste and drive more profitable behaviors. The platform also enables you to set thresholds, alerting conditions, and upload your own and/or third-party analytics.

Enjoy increased efficiency immediately through this digital connectivity. The combination of operational, maintenance, and aircraft data into one place will unlock value by enabling your airline to see line of sight into airline fuel and flight efficiency, maintenance, safety, block time analysis, and ground turn optimization.

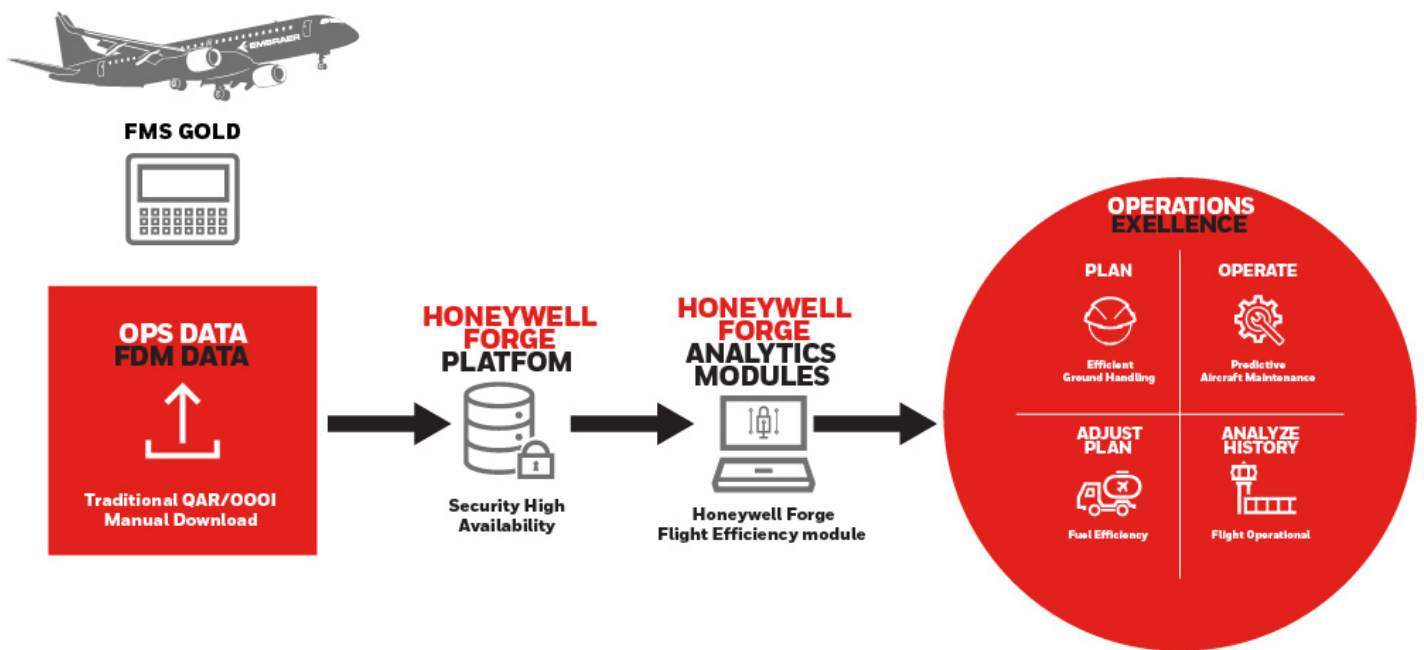
Fuel is the largest, or one of the largest cost factors in an airline. Depending on the airline, fuel costs represent 20% - 40% of the total costs of an airline. IATA states that an airline having a successful fuel-savings program can reduce its fuel costs by 2% to 5%.

The fuel conservation solution from Honeywell within Honeywell Forge for Airlines provides a full range of data analysis, reporting, and monitoring tools to help airlines achieve these savings. The Honeywell Forge Fuel Efficiency software performs the following main functions:

- Collects data automatically from the various data sources within an airline
- Checks and improves the quality of the data
- Provides sophisticated analysis-tools to identify fuel savings potential
- Provides tools to monitor the progress of the fuel efficiency improvement program
- Communicates the results to the stakeholders through various medium (email/EFB/intranet)



Honeywell recently completed a project with a North American regional airline that combined the enablement of the NGFMS Gold Option across the airline's Ejet fleet and the deployment of Honeywell Forge Flight Efficiency to measure the fuel savings attained through the consistent use of the Cost Index and Off-idle Descent functions enabled on the fleet. In conjunction with the modifications of the aircraft to enable the Gold functionality, Honeywell worked with the operator and their mainline partner to agree on a consistent and objective measure of fuel burn both before and after modification and transitioning to flying FMS-managed ECON speeds (Cost Index) in their operations. It was agreed and data was supplied by the airline to build a database of actual fuel burn over two years by their aircraft operating their route structure using the speed calculation and management capabilities of the Ejet legacy FMS before modification. As the historical data was analyzed, a process to collect and input aircraft data collected in current operations was implemented such that accurate, seasonally adjusted data that enabled same route, same period before and after analysis was enabled in Honeywell Forge Flight Efficiency. This process of defining the measurement methodology, inputting and cleansing the data, calculation and reporting the analytics was completed over roughly three months allowing reporting to begin with a small portion of the fleet completing the modification. Figure 3 provides a top-level system diagram of Honeywell Forge implementation with key functions highlighted.



- HONEYWELL FORGE CONNECTED BENEFITS:**
- Measure fuel savings and block time initiatives
 - Identify savings associated with aircraft investments
 - Help airlines build business cases for equipage

Figure 3. Honeywell Forge for Airlines operational cost savings

The entire fleet was modified roughly six months after initiation of the project with regular quarterly reporting established by that time.

The operational changes at the airline to implement the use of Cost Index and ECON speeds was greatly simplified given the NGFMS Gold implementation: with Gold enabled and a CI entered by the crew, the calculated ECON speed is the default FMS-managed speed in Climb, Cruise and Descent. The airline implemented a straightforward cost-indexing strategy at the outset, using their established cost of fuel and cost of time to set two indices: one for on-schedule operations that optimized fuel burn within planned block time assigned for the flight, and a second for scheduled recovery that, when used, would increase target speed at the expense of additional fuel burn to get the event back on schedule.

The flight crew would choose the appropriate CI for each flight with guidance from dispatch, enter it during performance initialization of the FMS during preflight knowing that the continuously updating ECON managed speed was optimized for the selected objective. In conjunction with the Gold enablement, the airline also took advantage of the AOC datalink improvements that allowed uplink of FMS winds and temperature aloft data. The ECON speed calculation takes advantage of the Advanced Environmental Model best when it is fully loaded with data, winds and temperatures at four flight levels for climb, at cruise waypoints, and descent as the ECON speed target calculation utilizes this environmental data as described earlier in the paper.

Nearly 18 months into the initiative, a very clear picture has emerged of the benefits accruing to this operator in terms of fuel savings resulting from enabling Gold via the use of Cost Indexing and ECON speeds along with Off-idle descent. Given that the data used in development of the analytics is coming directly from the aircraft, the accuracy is beyond reproach. Considering seasonal variations caused by en-route winds, and averaged across flights of varying stage length typical of most regional airline operators of the Ejet, savings per flight are averaging approximately 100 lbs per flight across a typical year.

A VERY CLEAR PICTURE HAS EMERGED OF THE BENEFITS TO OPERATORS IN TERMS OF FUEL SAVINGS. ENABLING GOLD HAS DELIVERED SAVINGS AVERAGING APPROXIMATELY 100 LBS PER FLIGHT ACROSS A TYPICAL YEAR.



CONCLUSION

As outlined in the introduction, operational necessities have resulted in many E-Jet operators developing alternatives and workarounds for the Cost Index and ECON speeds and Off-idle Descent capabilities provided by the NG FMS Gold option prior to its availability.

For this reason, calculating generalized cost savings provided by these features is not possible. There is not a “one-size-fits-all approach,” unfortunately in quantifying all the potential operational benefits the airline will realize by enabling the Gold option on their E-Jet fleet in conjunction with the upgrade to Load 27.1 and NG FMS. Rather, each airline’s potential savings will have to be estimated taking into account the nature of their E-Jet operations today, and improvements that can be made through deployment and use of the Gold features in their day-to-day operations.



Particularly in established airlines where the use of Cost Index has been institutionalized with the Boeing and or Airbus fleets, it is highly likely that Flight Operations has implemented some methodology for providing additional airspeed selection guidance to crews to augment the LRC calculation and speed management provided by the legacy E-Jet FMS. Some airlines have included suggested speeds for each leg of the flight in the briefing package provided at preflight with procedures in place to have the aircrew overwrite the legacy FMS-calculated LRC with a wind-corrected approximation of an ECON speed. Although this may provide some limited benefits in terms of aligning individual flight operations of the E-Jet with the cost control strategy, the automation provided by the NG FMS Gold option presents the opportunity for significant improvement in achieving that goal in a more standardized manner with consistency across each and every flight.

As outlined previously in the Cost Index section, Cost Index is not necessarily limited in its capability to reducing total trip fuel. It can in fact be used to keep the airlines operating network 'on schedule' by optimizing the operation of each flight in accordance with the airlines strategy which may or may not include consumption of minimum trip fuel, and it can be implemented much more effectively tactically (day of departure) through crew input of a single FMS parameter for an entire flight or even leg-to-leg to ensure conduct of each flight operation in accordance with the airline's optimization strategy applied to each flight as necessary. Utilizing the FMS Cost Index function dispenses with the need to maintain speed schedule tables with manual correction for head or tail winds, allowing the flight deck crew to focus on other tasks and greatly increasing crew adoption. Earlier in the paper, the NGFMS Performance Model implementation was outlined in detail. The Aero/Engine data utilized by the model was provided by Embraer and is the most precise data available for this purpose. The FMS implementation is able to more accurately consider winds aloft variation across the route of flight in the calculation of the ECON speed whereas manually-entered target speeds can only approximate the wind correction calculation.

For descent path construction and management, similar approaches have been developed by E-Jet operators. The legacy FMS has a rather simplistic descent path creation logic that is based on the Flight Path Angle selected for the descent path. There are, however, operational techniques that can be applied to make the legacy system emulate an idle approach using aircraft gross weight, altitude and forecast winds to adjust the Flight Path Angle and ToD that results in an idle descent. The Gold option of course totally automates the necessary calculation and operates the aircraft automation systems to maintain the optimum path, increasing fuel economy and passenger comfort during the approach phase.

Honeywell Forge Fuel Efficiency provides a powerful tool to the airline with advanced analytics using data from the aircraft to quantify the benefits and document the return on investment. Implementing Honeywell Forge for Airlines in conjunction with a fleet-wide upgrade is an excellent way to document the payback of NGFMS Gold, and provide a methodology for measuring and quantifying the value of other fuel saving initiatives associated with both modifications to the aircraft as well as change in operating procedures.

In conclusion, the Gold option offers airline operators functionality that improves operational efficiency of their E-Jet fleet today through automation that provides consistent and repeatable performance.

For more information

For more information on Honeywell's Epic Load 27.1 NGFMS for the E-Jet please contact your Honeywell sales representative or call +1 800 601 3099 or +1 602 365 3099.

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**THE
FUTURE
IS
WHAT
WE
MAKE IT**

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