DCS: Flight Modelling (FM) principles

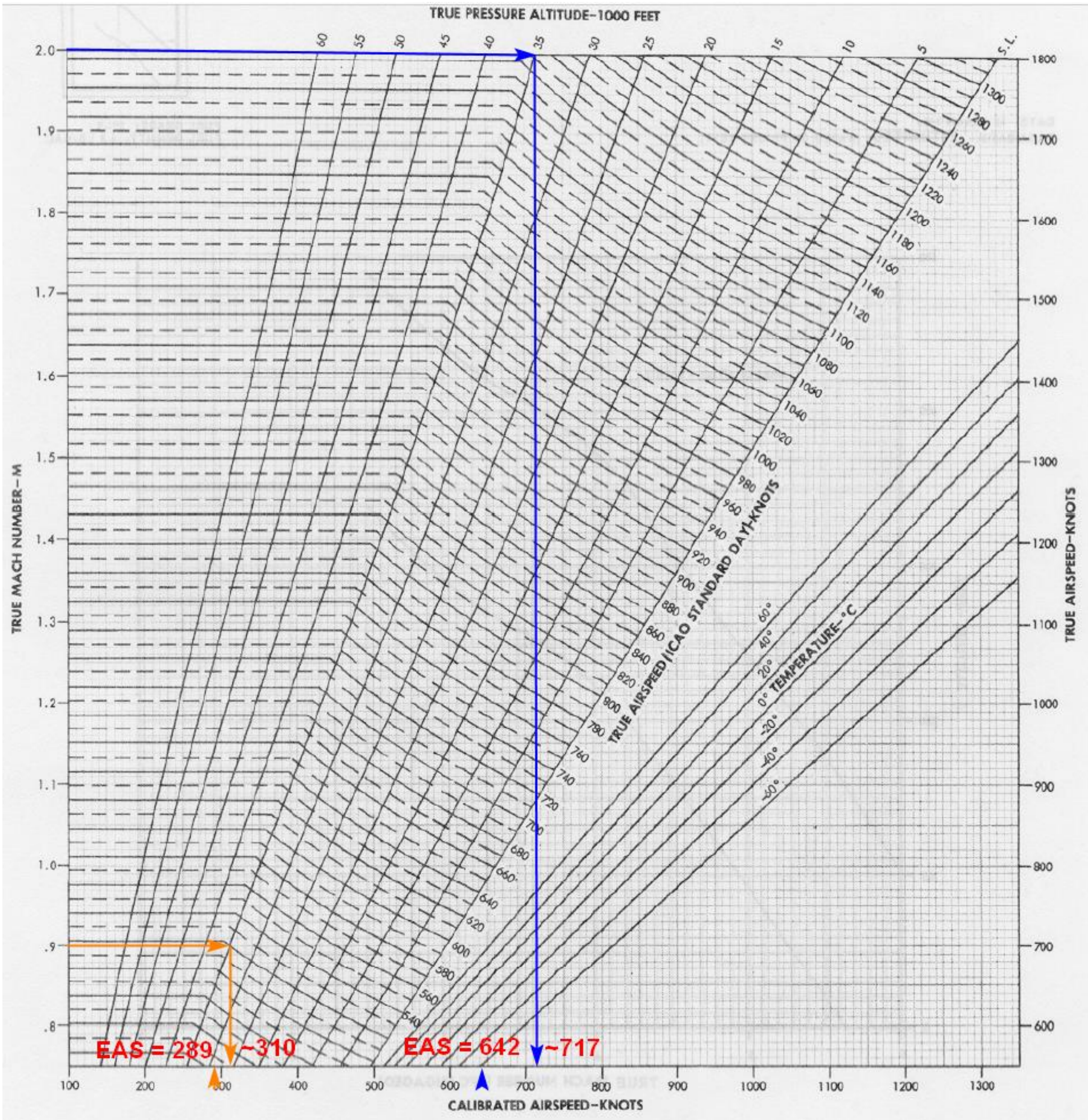
Airspeeds

Some background.

In aviation different speeds are used.

- True airspeed (TAS) - the speed of the aircraft relative to the airmass in which it is flying.
- Indicated airspeed (IAS) – the Airspeed Indicator readings that are uncorrected for position error, instrument error, installation error and compressibility.
- Calibrated airspeed (CAS) – which is IAS corrected for position error, instrument error, installation error but **not** compressibility.
- Equivalent airspeed (EAS) - defined as CAS corrected for compressibility but also it can be defined as a speed at sea level, ISA conditions, producing the same incompressible dynamic pressure that is produced at the true airspeed and the altitude at which the vehicle is flying. This speed is very convenient for aerodynamic calculations and can be used to calculate TAS in flight.

As a rule of thumb: EAS is numerically equal to CAS and TAS at sea level under ISA conditions, and at altitude EAS is always less then CAS and the difference is proportional to the Mach number.



For example, at 35'000 ft and Mach 0.9 the CAS is 310 kts, EAS is 289 kts, but at Mach 2.0 CAS is 717 kts and EAS is 642 knots which is calculated separately using the following formulas:
TAS = Mach * a, where a = 296.5 m/s is a sonic speed at given outside air temperature (-54C for ISA 35000 ft) ,
EAS = TAS * sqr (Rho/Rho_0), where Rho = 0.38 for ISA 35000 ft

How the FM is developed in DCS

With any FM, whether it be relatively simple flight model (SFM) for AI aircraft or the much more sophisticated Professional FM (PFM), they both start from two basic forces that act on the airframe: LIFT and DRAG.

Aerodynamic sciences use non-dimensional coefficients :

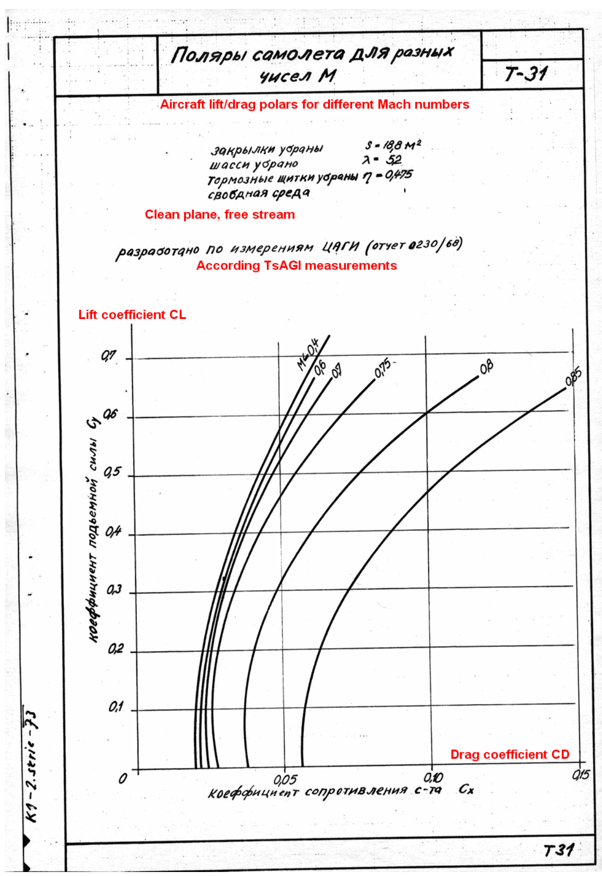
CL = Lift/q/S and CD = Drag/q/S, where q = Rho*TAS^2/2 (where Rho is actual air density) and where S is a specified wing area for the particular aircraft.

When EAS is known (or is used) then q = EAS^2*Rho_0/2 where Rho_0 = 1.225 kg/m3 is sea level air density under ISA conditions

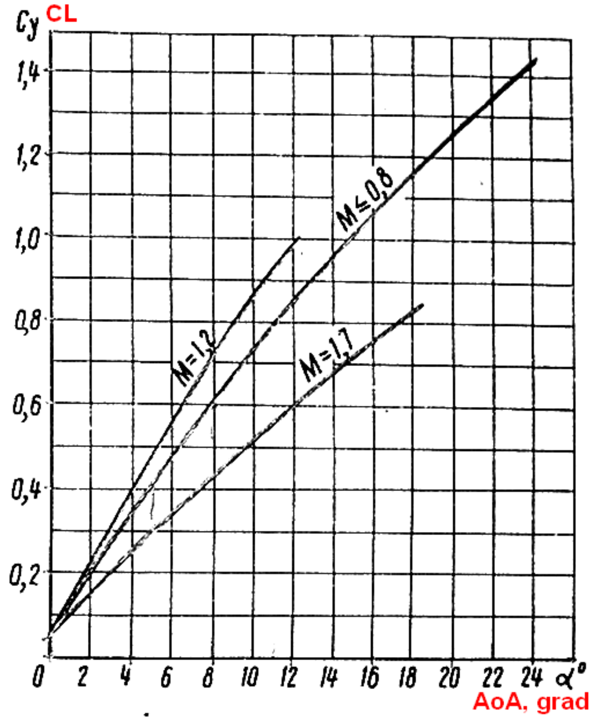
The **forces** are obtained in different ways: a) using physical wind tunnel data b) experimental flight test data and c) computational flow dynamics (CFD) methods. The **forces** are measured or calculated and then CL and CD are calculated.

CL and CD are functions of angle of attack (AoA), but it is convenient to have them in the form of CL = f (AoA) and CD = g (CL). The last one is known as **Lift/Drag polar plot**.

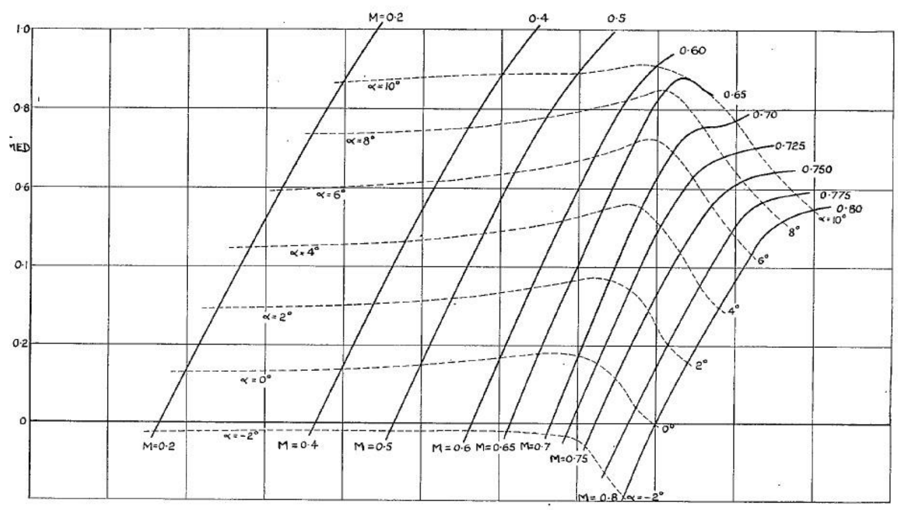
CL = f (AoA) and CD = g (CL) depend on several factors, for example: flap position, undercarriage position and Mach number (TAS divided by speed of sound). So, the necessary sets of CL and CD data become more and more complicated.
Here is an example of L/D polars we use as the foundation of our FM (in this case L-39 Albatros):



And CL versus AoA for Mig 29-A as an example:



Sometimes CL = f (AoA, M) is available in the form of so called “lift carpet”.



When using lift carpet sources, it is necessary to transform the data to a set of graphs in the same system of coordinates, notably AoA and CL.

When designing our FM it is necessary to place our **aircraft mathematical model** into a **virtual wind tunnel**, obtain the **force coefficients** and match them to the documented reference coefficients. At this stage, **no** airspeed is used at all in the process except dimensionless Mach number (essentially a ratio) which is used to establish the different sets of aerodynamic coefficients.

As well as forces, **moments** are obtained from the experimental test data or CFD calculations and they are converted to dimensionless coefficients of moments using mean aerodynamic chord length and wing span as a specified length:

m_pitch = M_pitch/q/S/MAC (this can be obtained either versus AoA or CL)
m_yaw = M_yaw/q/S/Wingspan (this is usually obtained versus Angle of Slip AoS)
m_roll = M_roll/q/S/Wingspan (this is usually obtained versus AoS)

Here is an example of wind tunnel tests for pitching moments at various Mach numbers.

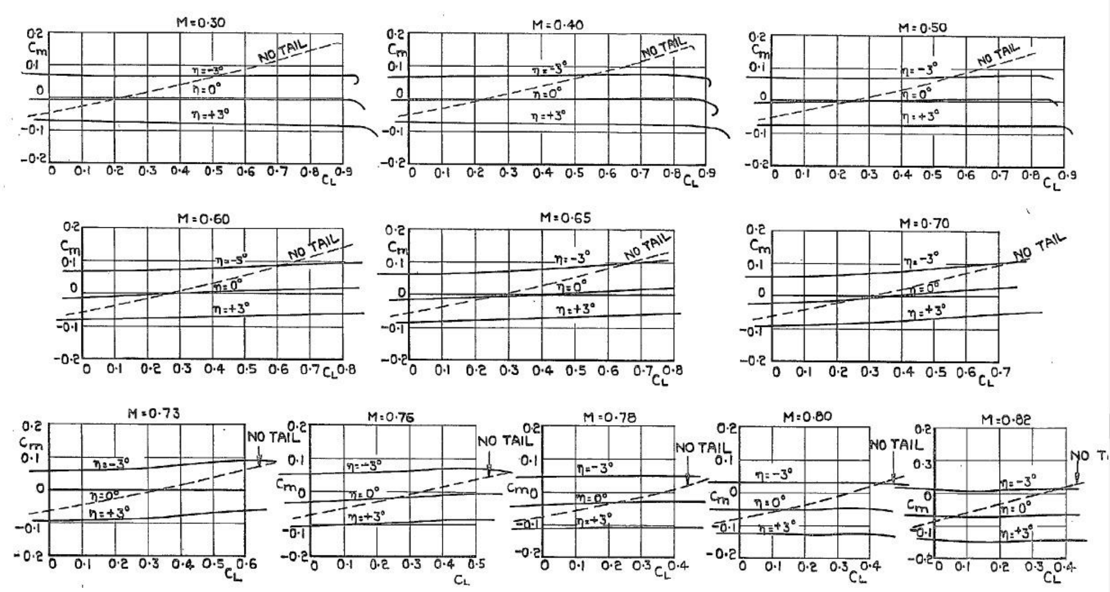
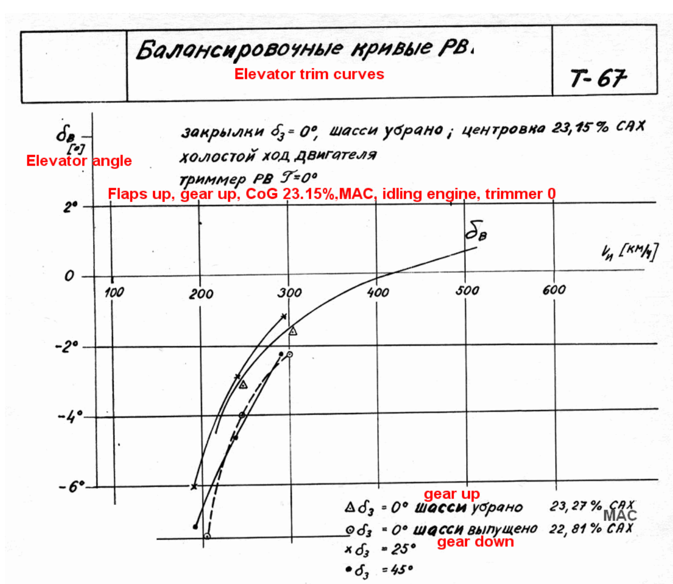


FIG. 12. Pitching-moment curves—complete model, $\eta_T = -\frac{1}{4}$ deg.

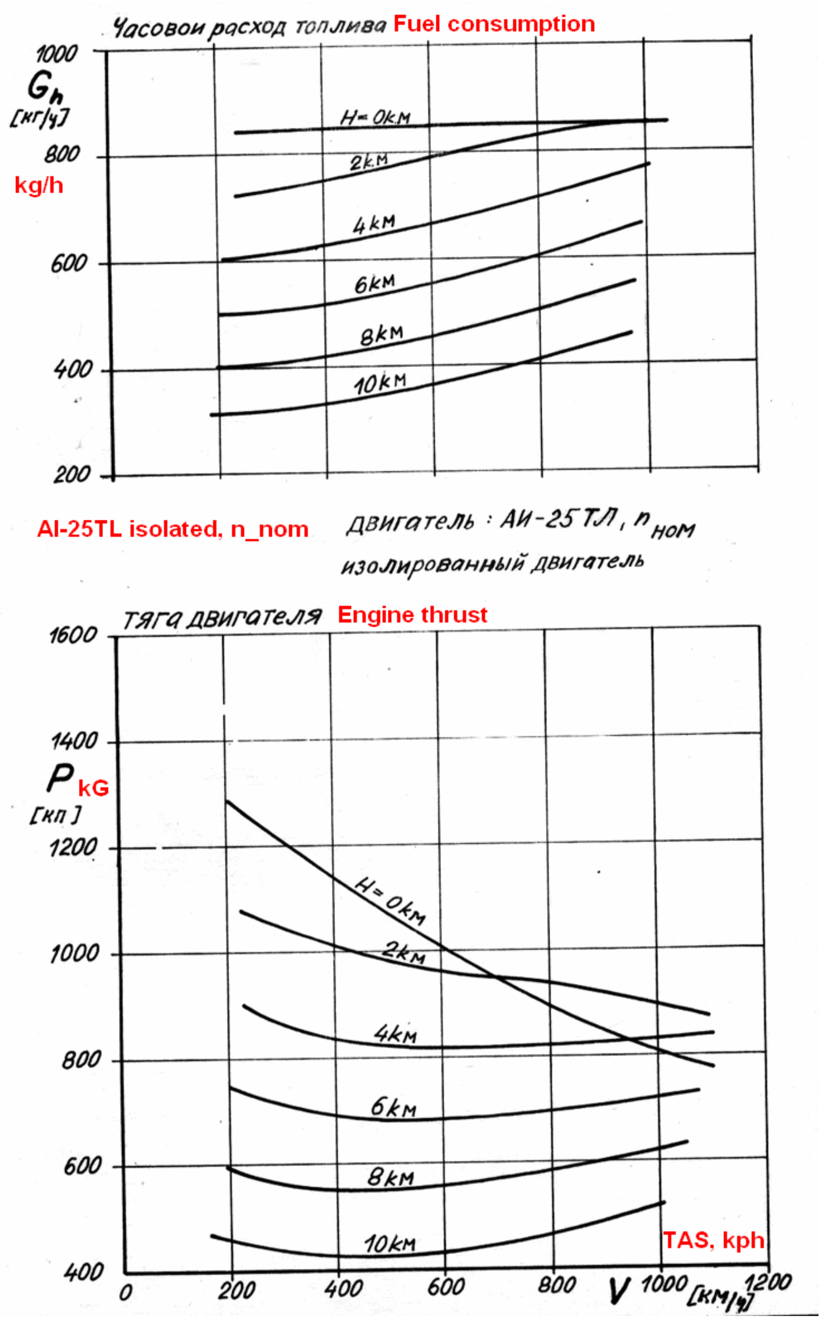
Once again, no speed is required as only **dimensionless coefficients** are used.
In certain circumstances, there is a need to obtain moment characteristics of the specific aircraft from flight test data. For example: trim curves or elevator position for 1g level flight:



This is **elevator angle** that is required for level flight versus **airspeed**. Note that this is the first case where we have speed as an argument. This graph uses INDIKATORNAYA speed that is an equivalent of EAS not IAS. In this case, the task is relatively straight forward as all we need to do is convert this speed to CL as described above.

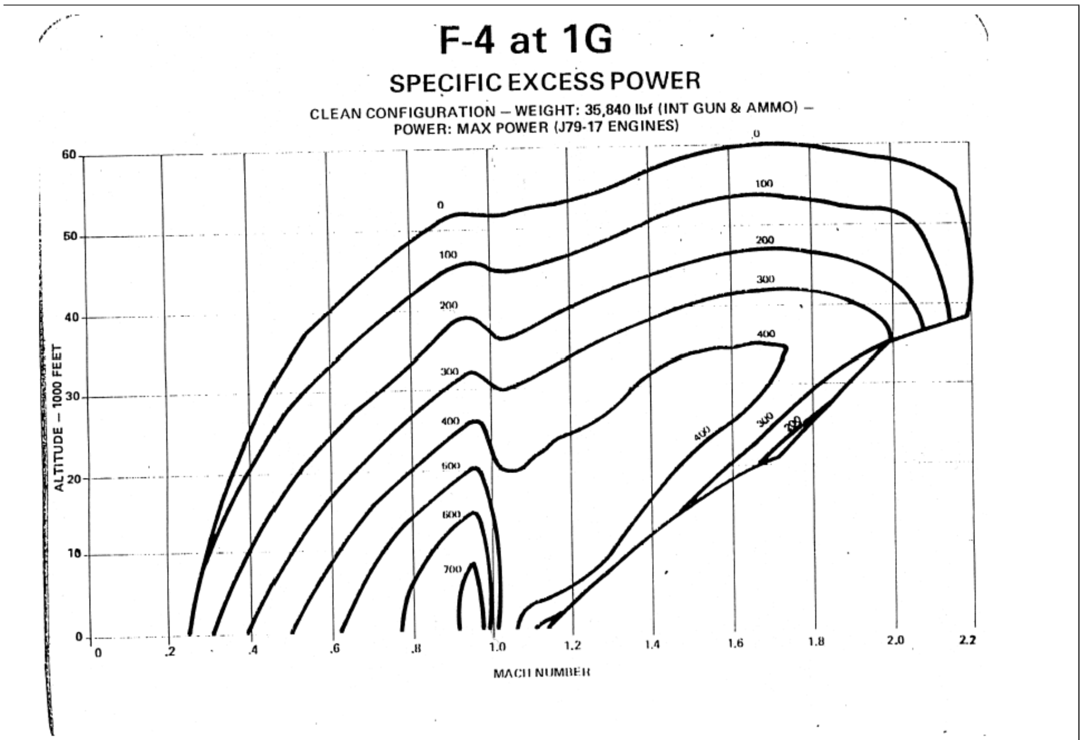
CL = m*g/(S*q), q = (Vи /3.6)^2*1.225/2
Where m= is mass and g=9.81m/s/s

The third corner stone of our FM is thrust (for jets).



If such graphs are available, there is no problem to convert TAS (V in this source) to Mach number for each altitude and then use it directly for SFM or to use it as a reference for our thermodynamic model for PFM using either Mach or TAS directly.

The most complicated task is to derive the thrust curves and L/D polars from performance charts. This is an example of the most useful chart:



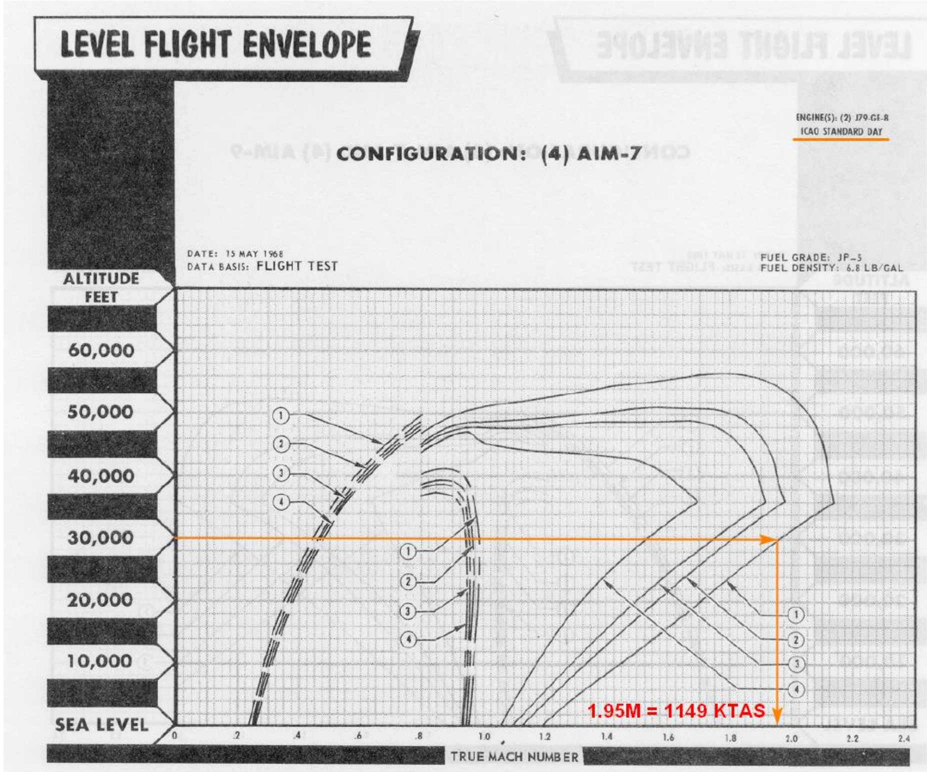
As this chart is plotted vs Mach number, a simple conversion is required to obtain TAS at a specific altitude using speed of sound at specific altitude and then use TAS with altitude air density for further calculations.

Sometimes similar graphs are plotted vs CAS. The task to convert CAS to TAS can be solved converting CAS to Mach number at the specific pressure altitude and then as described above.

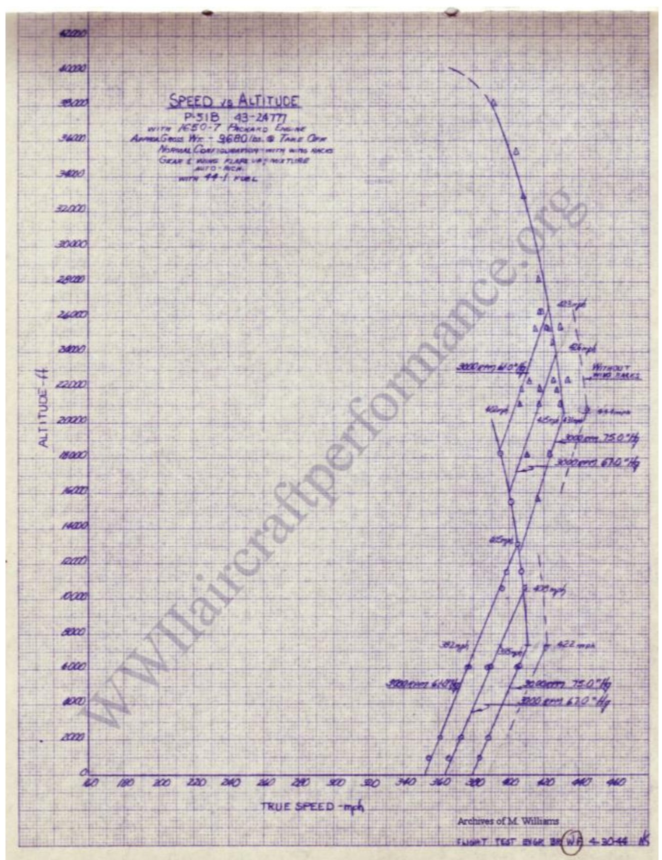
How the FM is verified and tested

Each plane we model has its own set of reference data for charts, graphs, etc. All of were plotted against different airspeeds: Mach number, TAS, EAS, CAS and even IAS.
To compare FM with the real aircraft the most convenient is TAS, because absolute velocity exported from DCS engine without wind is numerically equal to aircraft TAS.

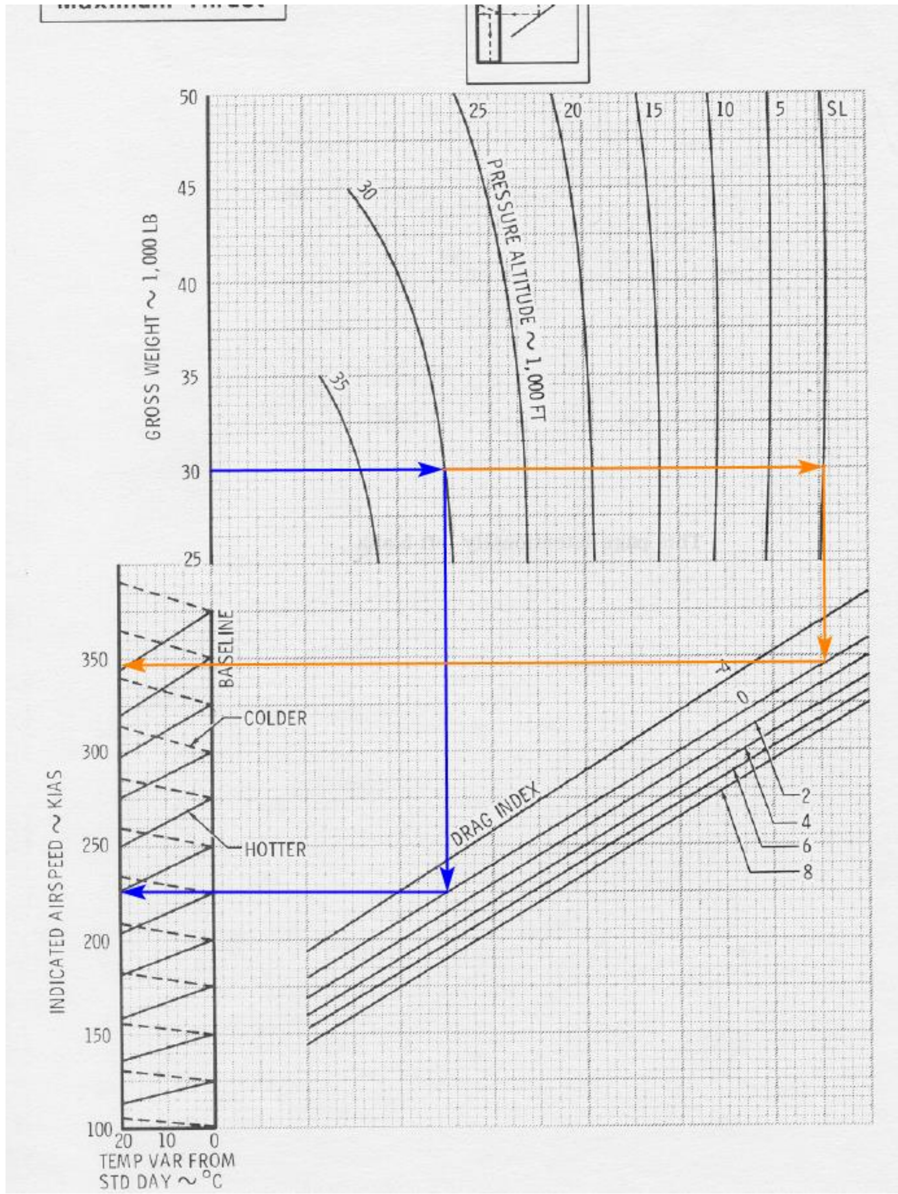
In the diagram below for F-4 Phantom with 4 AIM-7 attached, the Mach number reference is converted to KTAS (true airspeed in knots):



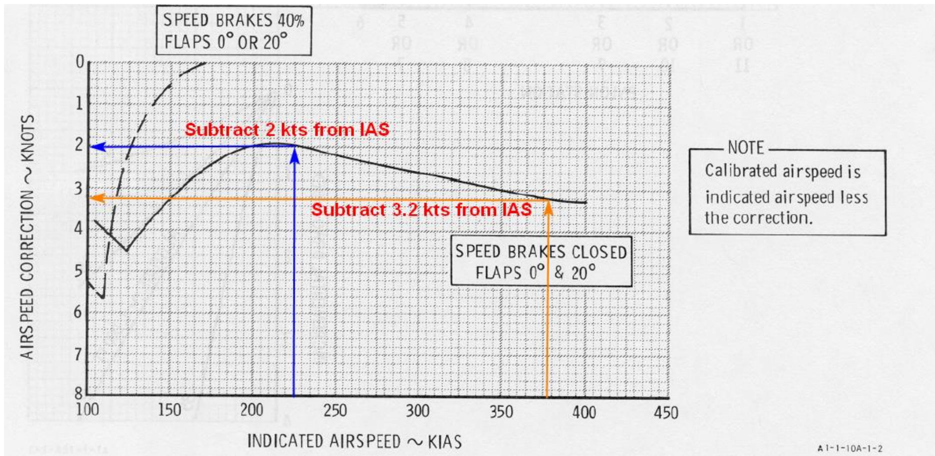
Below is a TAS chart where no conversion is needed (P51-B Mustang)



And finally, let us take a look at the very rare case where the speed is presented in Knots IAS. To convert this to TAS it is necessary to use position error correction (PEC) to obtain CAS, then correct for compressibility and then use altitude density to obtain TAS.
As an example below (A-10A Thunderbolt II), we need to find the reference values of maximal speed at SL and at 30’000 ft for a gross weight of 30’000 lb.



So Sea Level Knots IAS = 345 and at 30’000 ft KIAS = 225
Then by using PEC



At Sea Level KCAS = 342, 30'000 ft KCAS = 223
The correction for **compressibility** can be done only for 30'000 ft either using calculation or by the above mentioned chart.
SL KEAS = 342, 30'000 ft KEAS = 216
Then, using altitude density
SL KTAS = 342 , 30'000 ft KTAS = 354

Conclusions

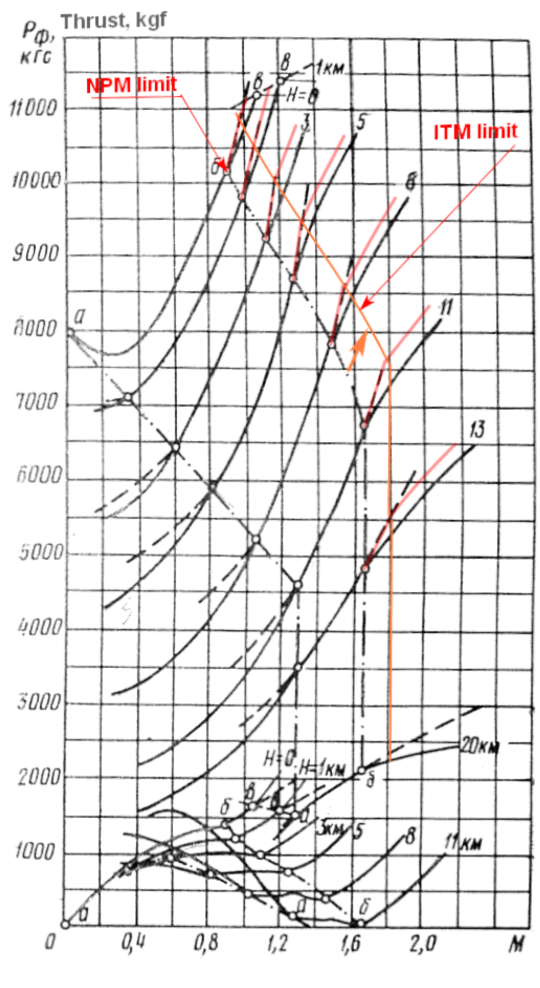
In DCS for standardized **EAS** for **indication** was used instead of CAS. This was a simplification which isn't reflected in all real aircraft. The difference is small in subsonic ranges, but it increases at high altitude and high Mach numbers.
Following the valuable post in Forums, where applicable and specified in real life, we will change cockpit indications to read **CAS**.
This change will be made available in coming update patches.
EAS will be left in the status bar for convenience alongside World Vector Speed.

NB. This purely indication issue does NOT affect DCS FM under any circumstances.

DCS MiG-29 FM verification

Engine modes

As DCS is a combat simulator where engine lifetime does not matter, the RD-33 engines are permanently switched to so called Increased Temperature Mode (ITM) increasing high speed thrust. At high Mach numbers rammed air in front of the compressor has high temperature, so the temperature after the compressor and the turbine inlet temperature (TIT) too. At the certain Mach number it is necessary to start limiting fuel flow avoiding turbine blades overstress. RD-33 engine has the training mode (Low Power Mode) and two combat modes – Normal Power Mode (NPM) and Increased Temperature Mode (ITM). The last one gives the highest performance at high Mach numbers but the lowest engine lifetime.

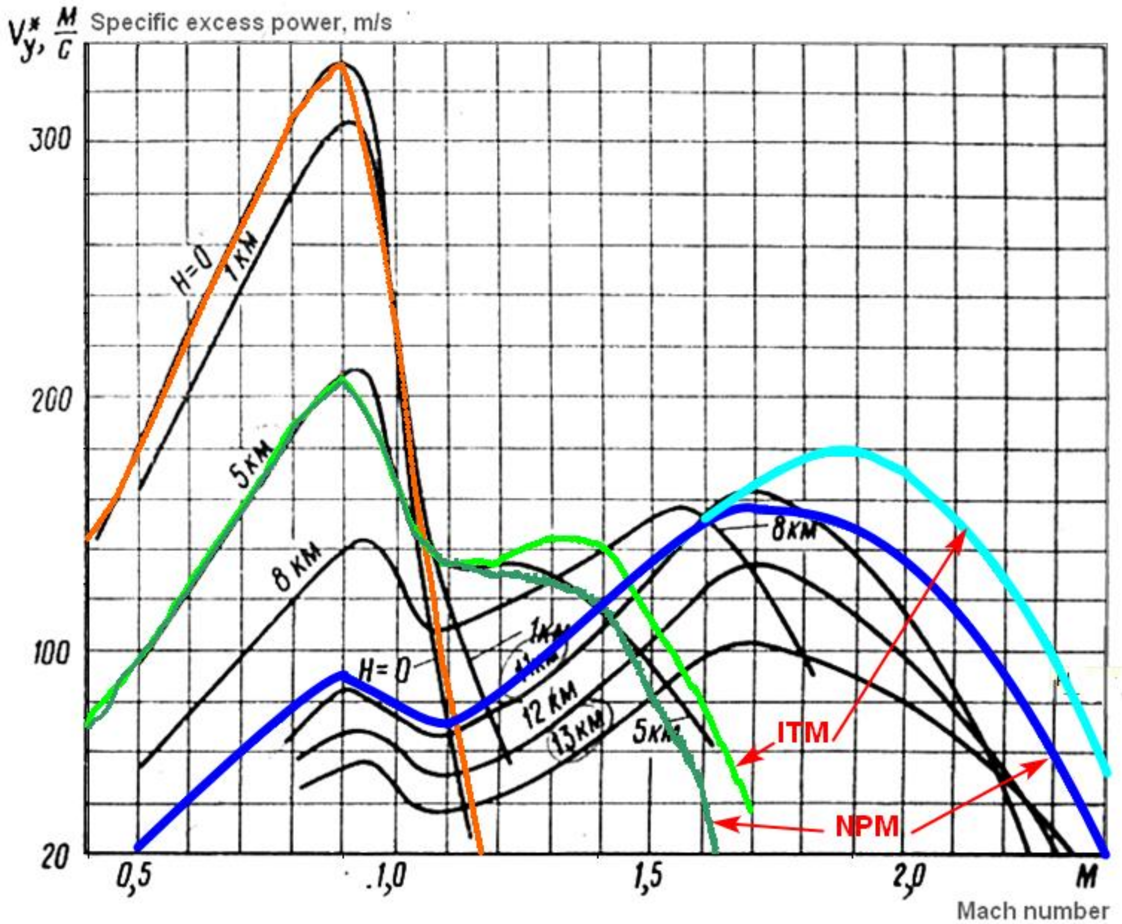


Engine thrust at Full AB

РИС. 3.17. ВЫСОТНО-СКОРОСТНАЯ ХАРАКТЕРИСТИКА
НА РЕЖИМЕ "ПОЛНЫЙ ФОРСАЖ"

Acceleration and Specific Excess Power in level flight

An aircraft can gain energy either climbing or accelerating, so it's convenient to express gaining of energy as pure climb at constant speed or as pure acceleration in level flight.
The first one is known as Specific Excess Power (SEP).
At the graphs below SEP for MiG-29 are shown for different altitudes. Reference curves were plotted for NPM thrust.

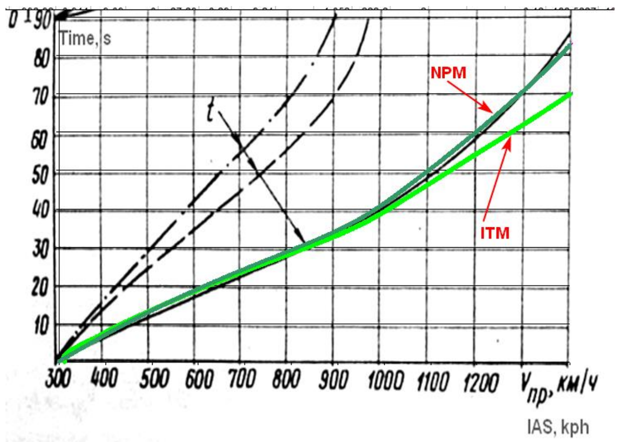


Specific excess power versus Mach number, full AB

РИС. 5.9. ЗАВИСИМОСТЬ ЭНЕРГЕТИЧЕСКОЙ СКОРОПОДЪЕМНОСТИ ОТ ЧИСЛА М И ВЫСОТЫ ПОЛЕТА ПРИ РАБОТЕ ДВИГАТЕЛЕЙ НА РЕЖИМЕ "ПОЛНЫЙ ФОРСАЖ" (самолет с 2хР-60МК И 2хАПУ-470, m = 13000 кг)

2 x R-60MK and 2 x APU-470, mass = 13000 kg

Acceleration curves at the graph below are recorded directly from DCS.

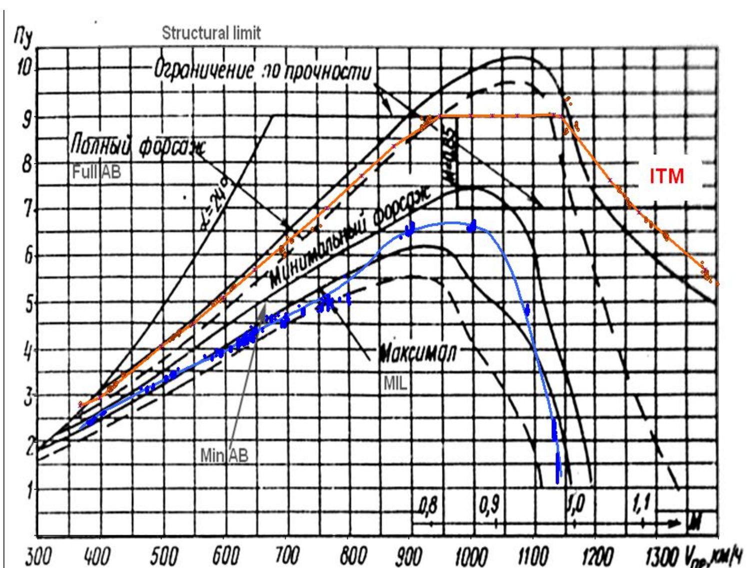


Acceleration at 5000 m

РИС. 6.6. ХАРАКТЕРИСТИКИ РАЗГОНА САМОЛЕТА БЕЗ ПОДВЕСОК НА H = 5000 М:

"Полный форсаж"; Full AB
"Минимальный форсаж"; Min AB
"Максимал" MIL

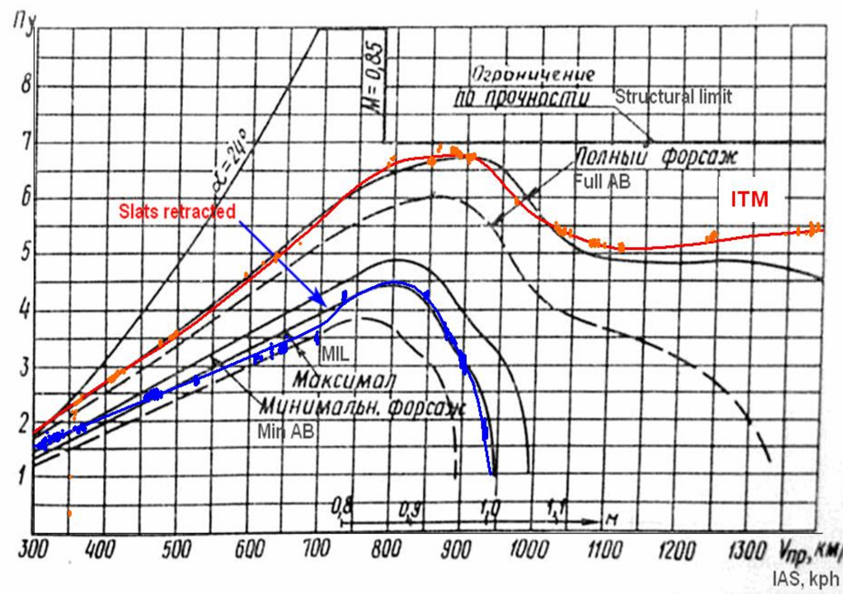
Sustained G turn capability



Sustained G turn capability max AB, min AB and MIL at 1000 m

РИС. 6.14. ПЕРЕГРУЗКИ ПРЕДЕЛЬНОГО ПО ТЯГЕ ВИРАЖА НА ВЫСОТЕ 1000 М В ЗАВИСИМОСТИ ОТ СКОРОСТИ ПОЛЕТА, РЕЖИМА РАБОТЫ ДВИГАТЕЛЕЙ И ПОДВЕСОК (m_T = 1500 кг): Fuel 1500 kg

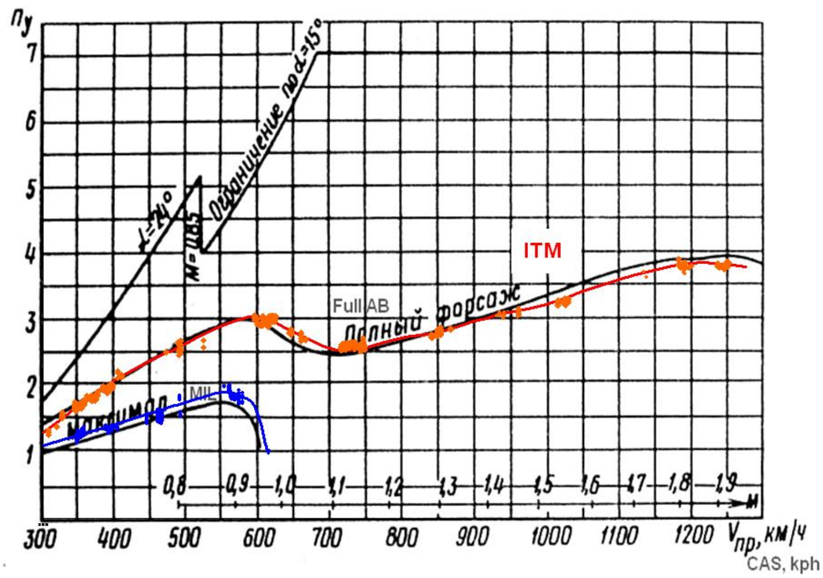
без подвесок; Clean
с 2хР-27Р1 и 4хР-60МК



Sustained G turn capability at 5000 m for full AB, min AB and MIL

РИС. 6.15. ПЕРЕГРУЗКИ ПРЕДЕЛЬНОГО ПО ТЯГЕ ВИРАЖА НА ВЫСОТЕ 5000 М В ЗАВИСИМОСТИ ОТ СКОРОСТИ ПОЛЕТА, РЕЖИМА РАБОТЫ ДВИГАТЕЛЕЙ И ПОДВЕСОК (m_T = 1500 кг): Fuel 1500 kg

——— без подвесок; – – – с 2хР-27Р1 и 4хР-60МК
Clean



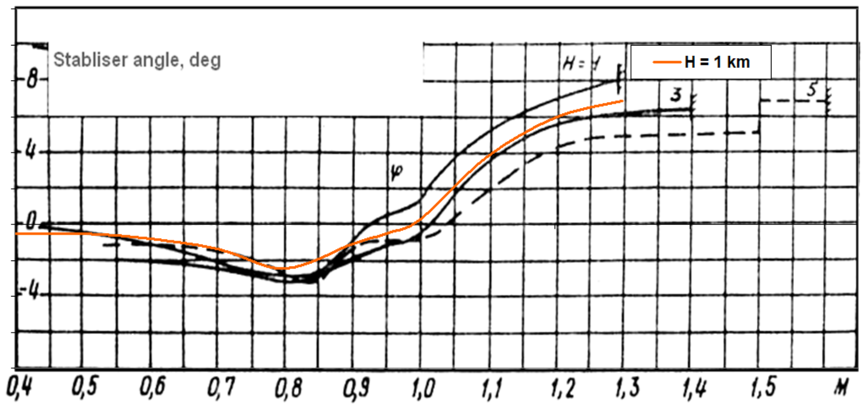
Sustained G turn capability at 11000 m for full AB and MIL thrust

РИС. 6.16. ПЕРЕГРУЗКИ ПРЕДЕЛЬНОГО ПО ТЯГЕ ВИРАЖА НА ВЫСОТЕ 11000 М В ЗАВИСИМОСТИ ОТ СКОРОСТИ ПОЛЕТА И РЕЖИМА РАБОТЫ ДВИГАТЕЛЕЙ (самолет с 2хР-60МК и 2хАПУ-470, m_T = 1500 кг)

Payloads 2 x R-60MK and 2 x APU - 470 Fuel 1500 kg

Aircraft trim

MiG-29 has thrust vector applied below CoG causing very pronounced pitch-up effect especially at low IAS and low altitudes. The chart below is for Full AB acceleration run.



Stabiliser angle for level flight at low and medium altitudes. The aircraft with missiles, CoG =27.5% MAC

РИС. 4.26. БАЛАНСИРОВОЧНОЕ ОТКЛОНЕНИЕ СТАБИЛИЗАТОРА В ГОРИЗОНТАЛЬНОМ ПОЛЕТЕ НА МАЛЫХ И СРЕДНИХ ВЫСОТАХ (самолет с ракетами, $\bar{X}_T$ = 27,5 % САХ)

Roll rate

ROLL RATE VERSUS MACH NUMBER

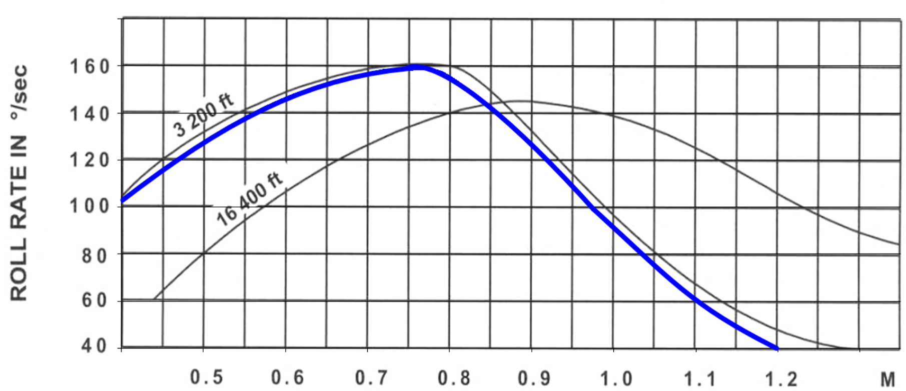
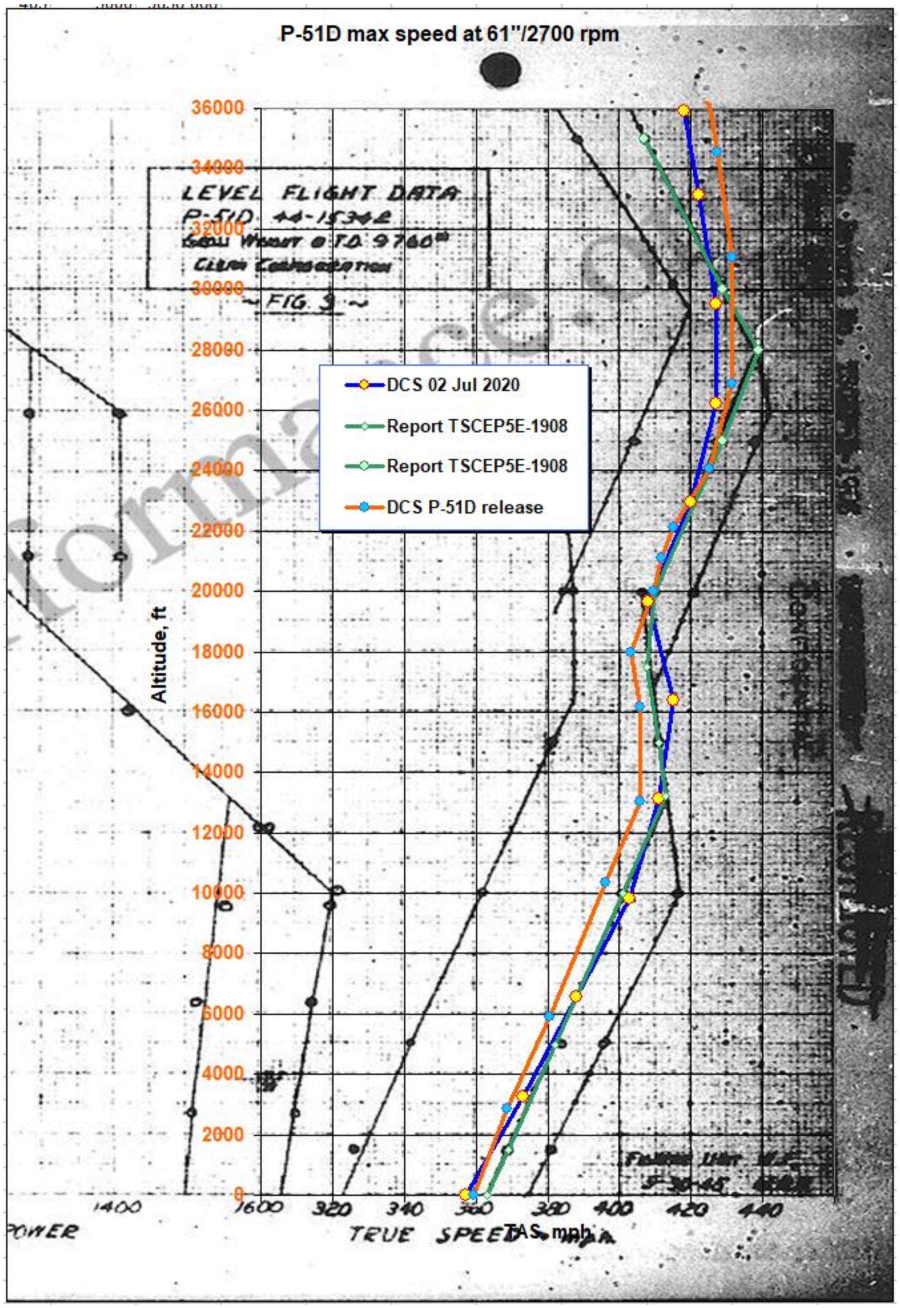


Figure 6-5

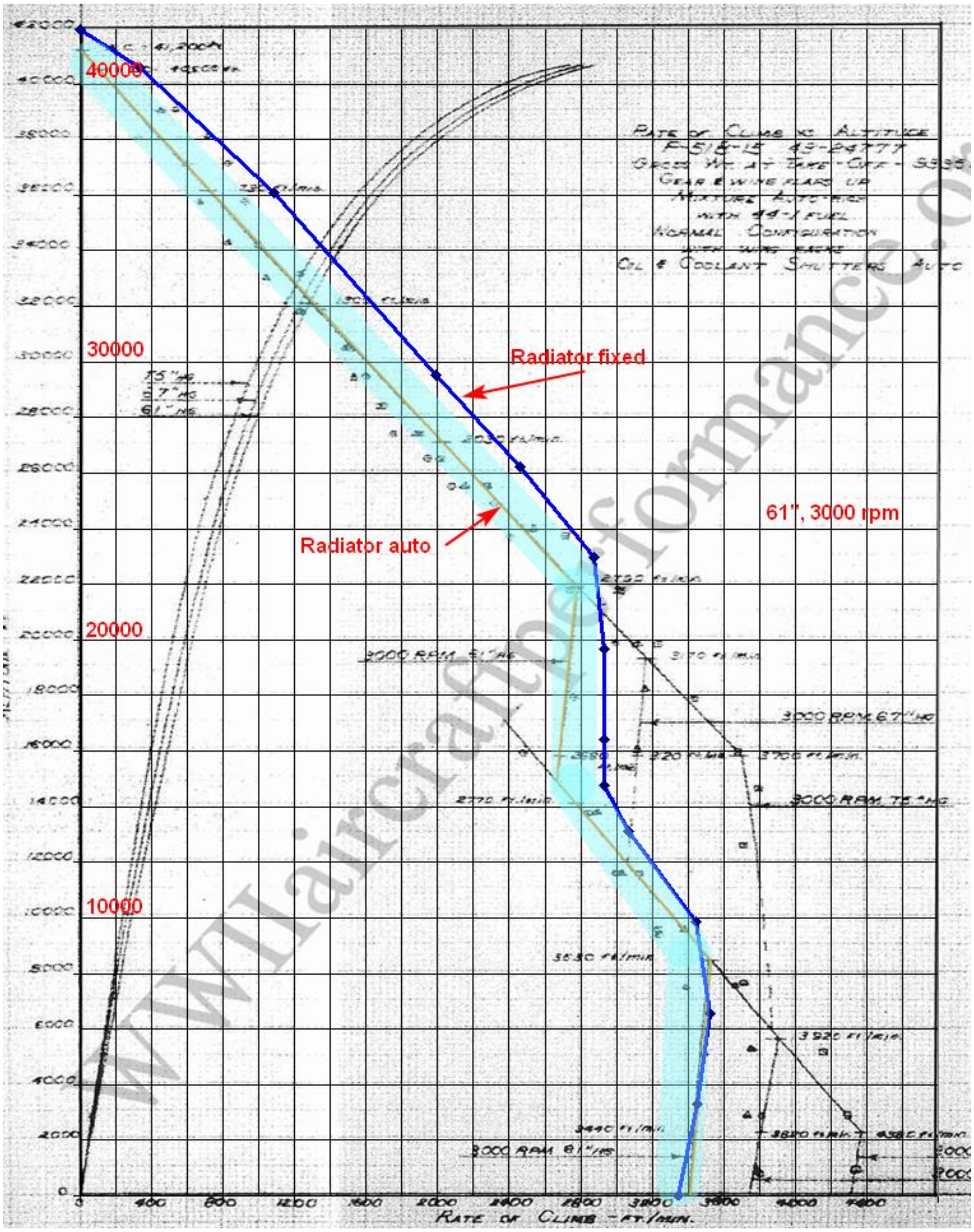
Mustang P-51

Level flight



For comparison release version of 2012 measurement results are included.

Climb



Blue line is Specific Excess Power (SEP) measured during acceleration with radiator in intermediate position (not sufficient for real climb). Light blue line represents climb rate for real climb with radiator in AUTO mode.

Roll

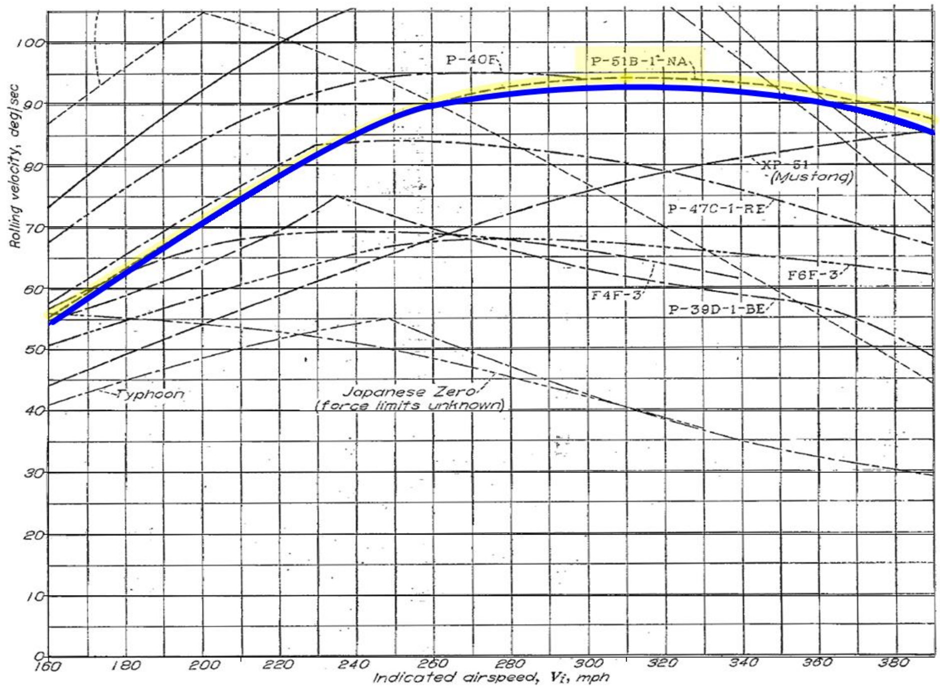
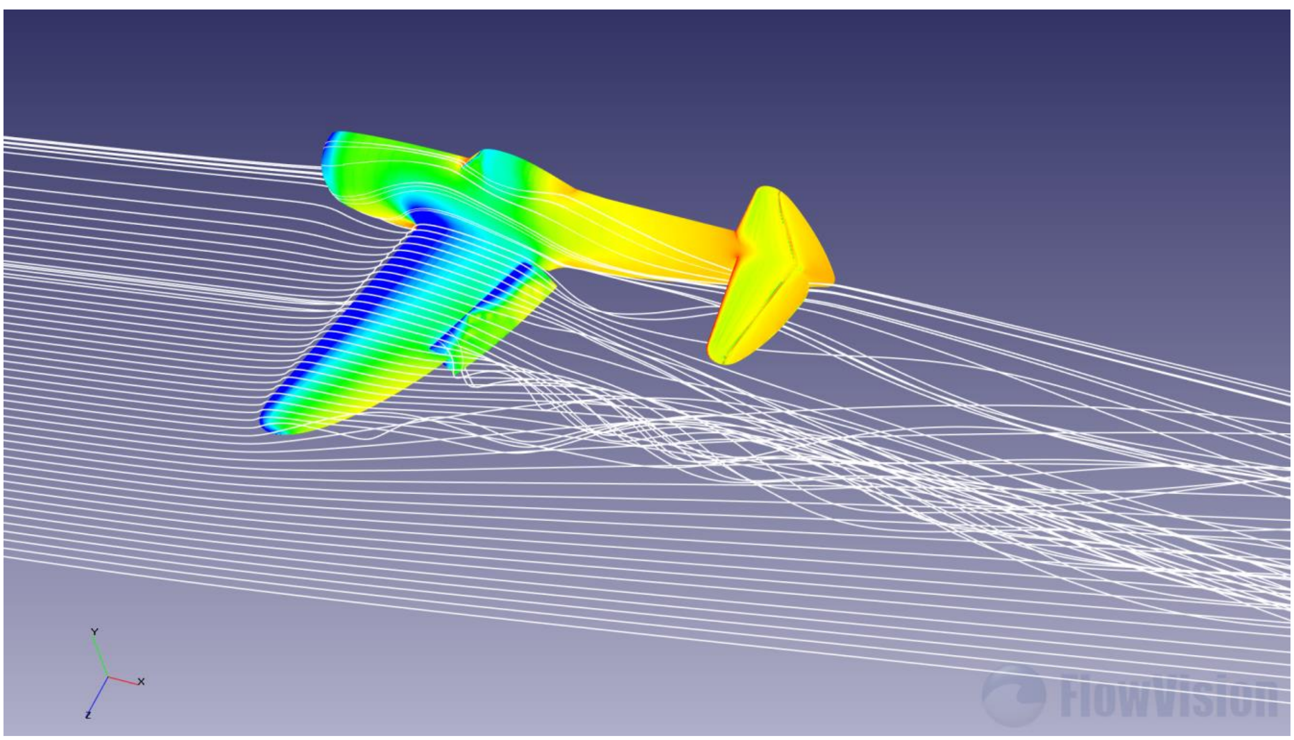
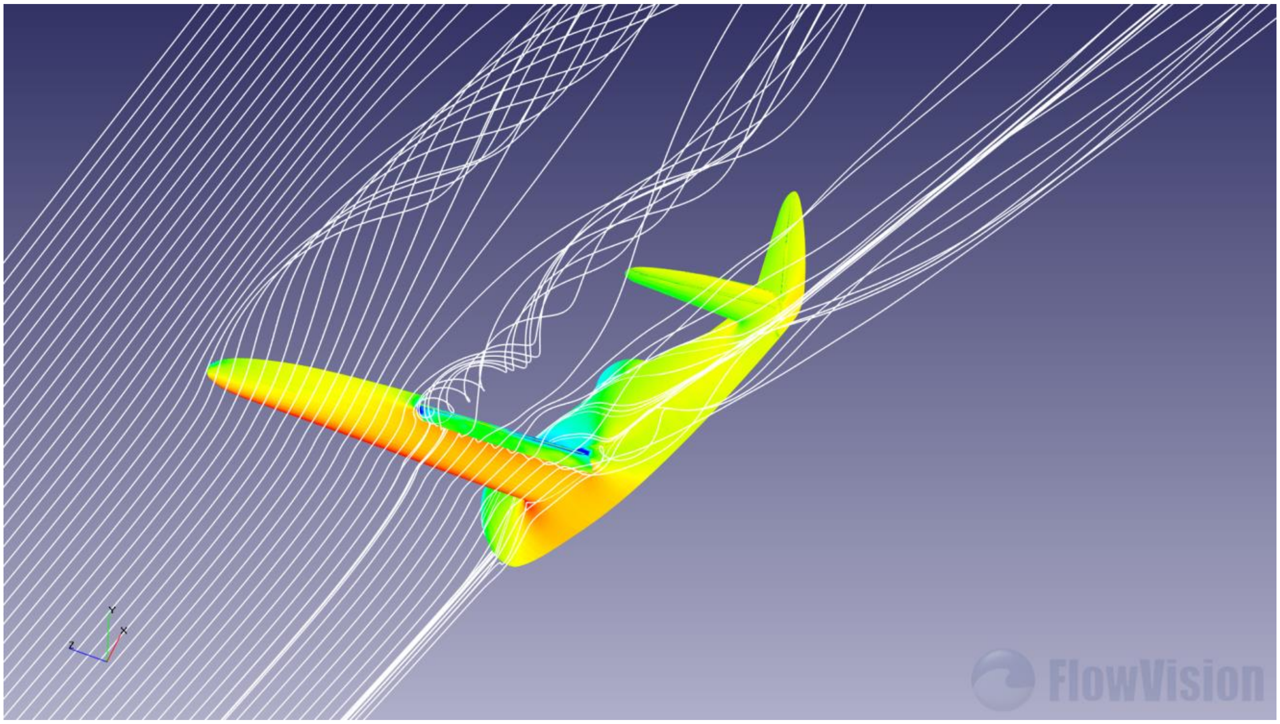


FIGURE 47.—Variation with indicated airspeed of rolling velocity obtainable with 50-pound stick force. Altitude, 10,000 feet.

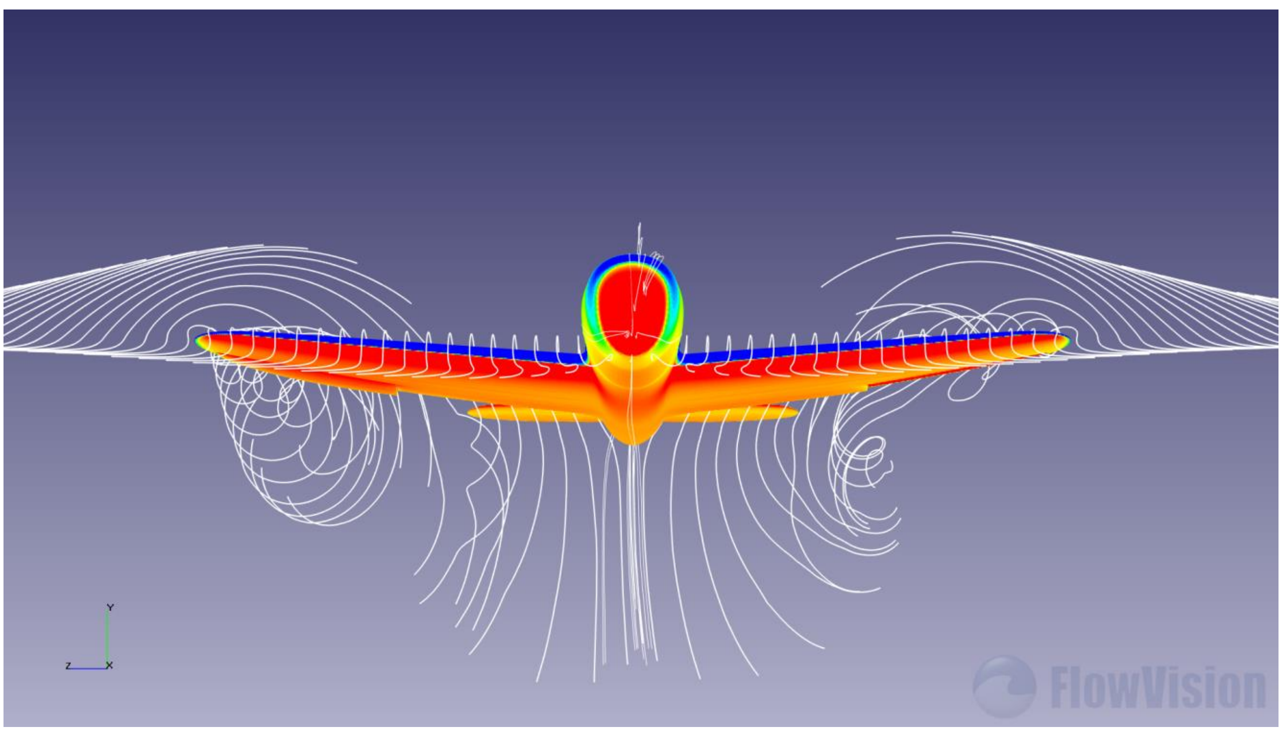
P-47 Thunderbolt virtual wind tunnel CFD tests

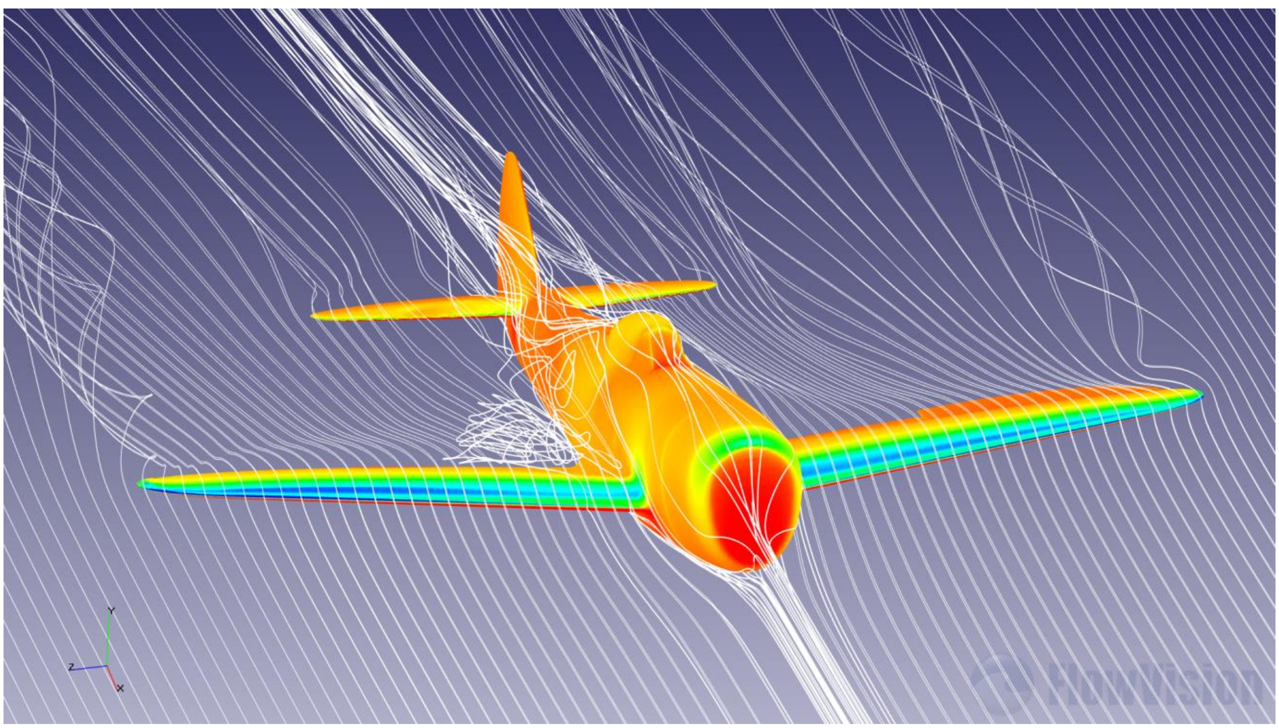
As we mentioned earlier P-47 wind tunnel data is not very detailed, so we had to add CFD measurements to obtain more detailed data for our FM.





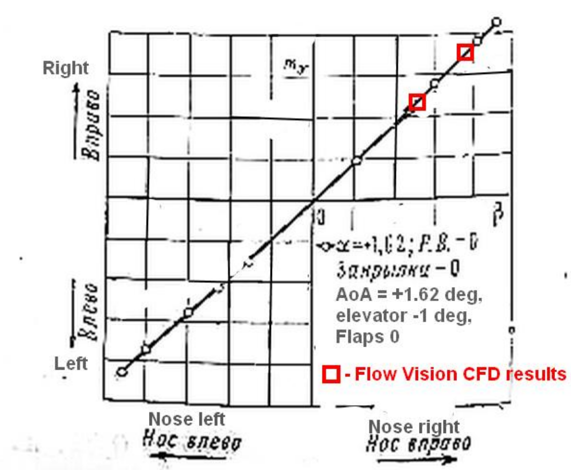
Computational fluid dynamics requires a lot of processing time to obtain results for a single case.
This half-model method for a symmetrical case allows to significantly save the time.
The next case with deflected ailerons is not symmetric, so the full model is used.





P-47D 3D-model for DCS visualization was based on factory drawings with ordinate tables that allow to obtain the shape with high accuracy – up to 0.001”, so, the model became a good base for various CFD tests. The flow lines plots above are not the main result of these tests – a lot of pitching, yawing and rolling moment coefficients were obtained, each of them – for several flight control surfaces position.
After P-47 FM had been completely finished based on available data and CFD tests, we managed to get P-47 model 5-feet wind tunnel tests conducted in the USA. Surprisingly, it was a Soviet report based on a translation of American report. Flow Vision results is added at the graph

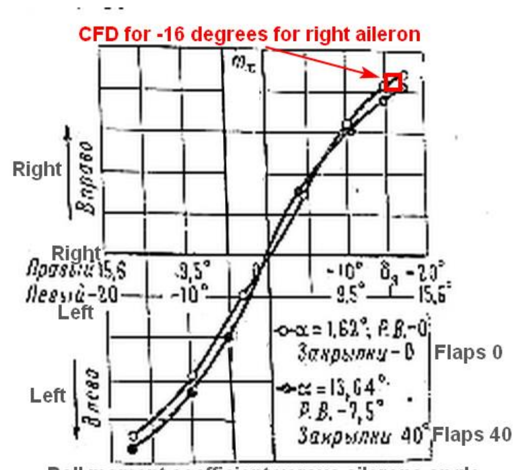
representing rolling moment coefficients versus yaw (note that the right roll due to nose right yaw is depicted positive, due to agreement of that time) and rolling moment coefficient versus aileron deflection.



Lateral moment coefficient versus yaw angle

Фиг. 10. Коэфициент поперечного момента по углу рысканья. Скорость потока 97 км/час. Стабилизатор +1°

Air flow velocity 97 kph Stabilisator angle +1 deg



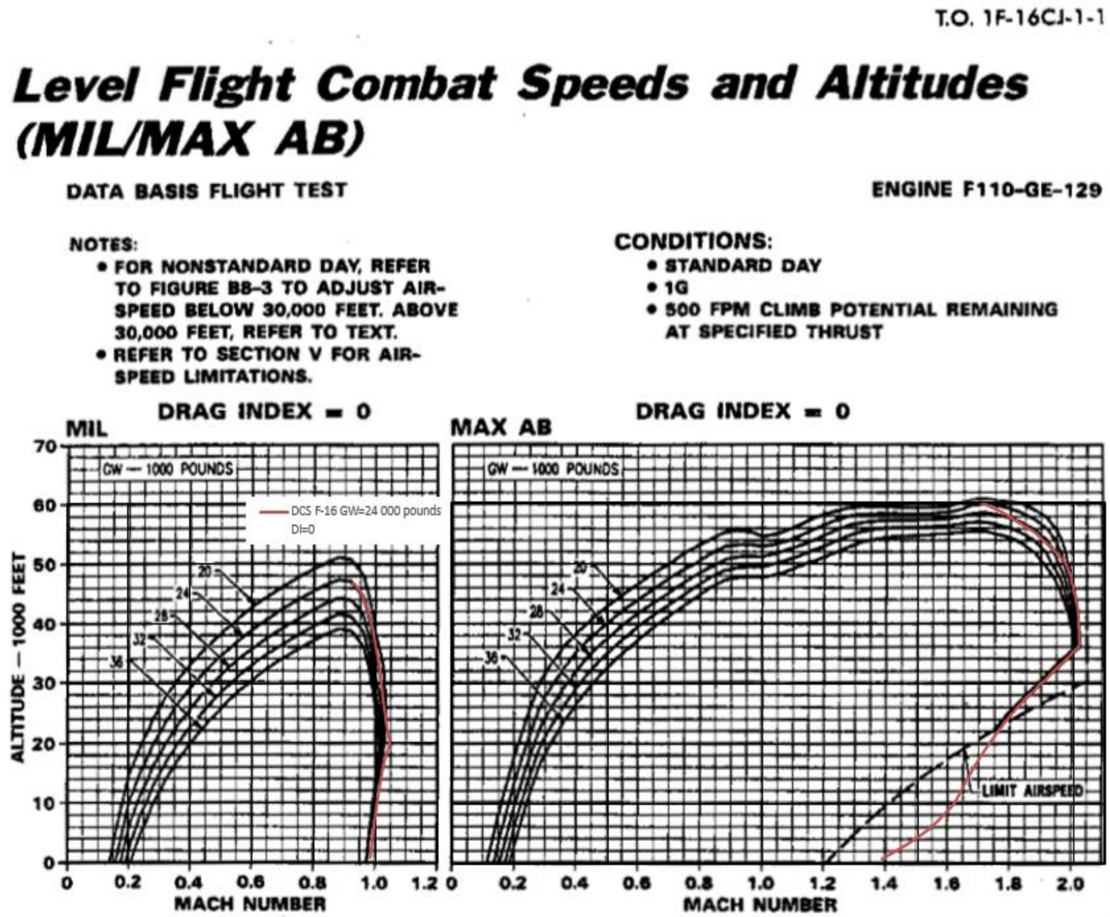
Roll moment coefficient versus ailerons angle

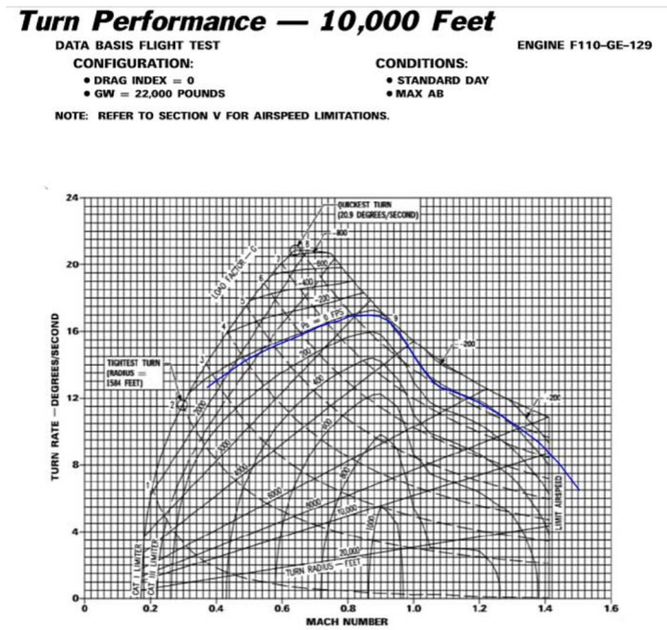
Фиг. 11. Коэфициент поперечного момента по углу отклонения элерона. Скорость потока 97 км/час. Стабилизатор +1°

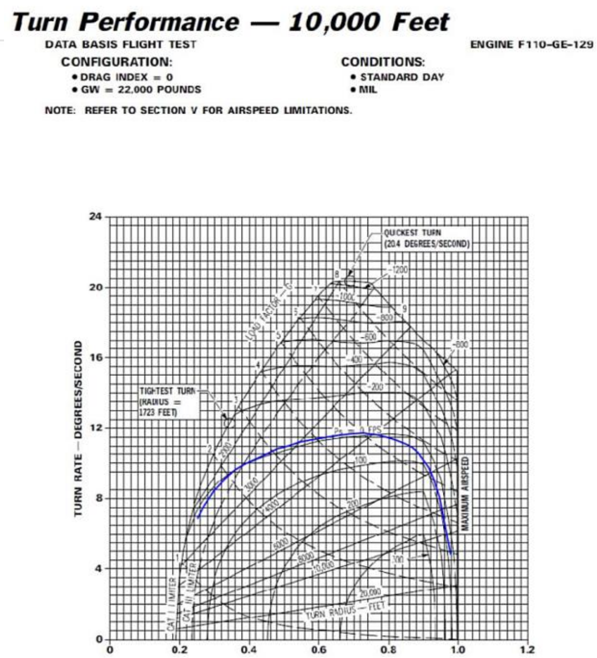
Air flow velocity 97 kph. Stabilisator +1 deg

F-16C FM verification

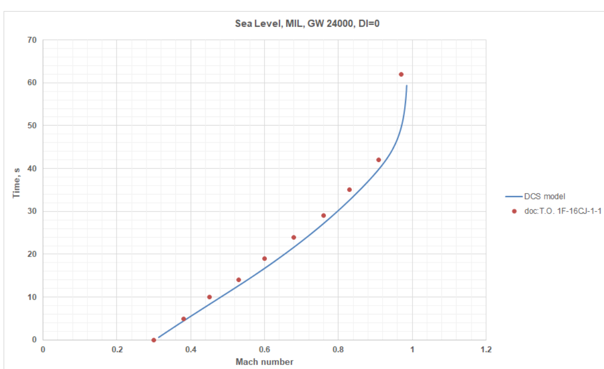
Flight envelope and turn performance

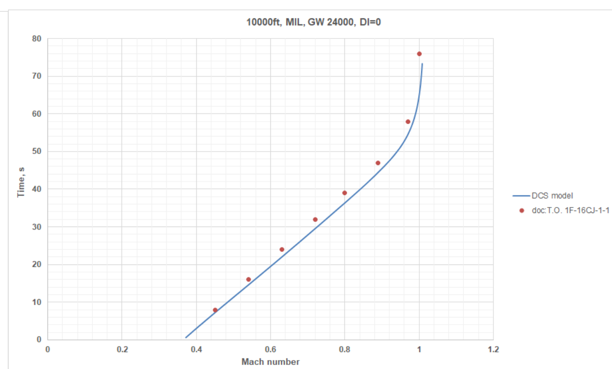


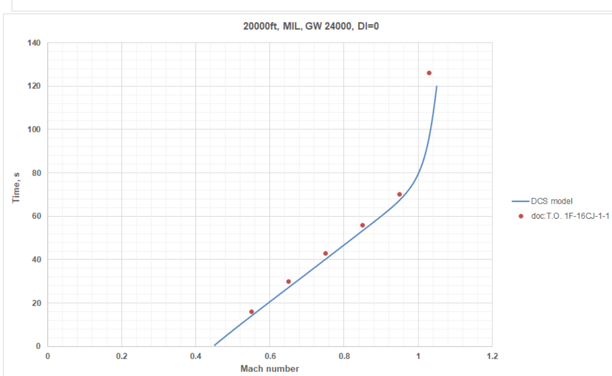


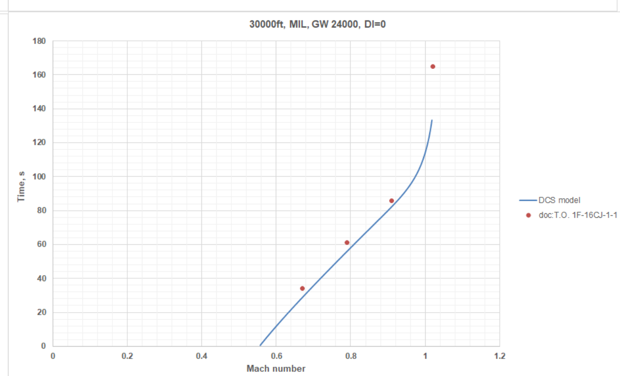


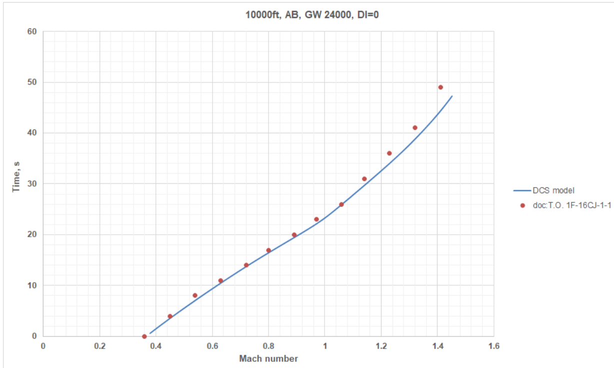
Acceleration MIL thrust and Full AB

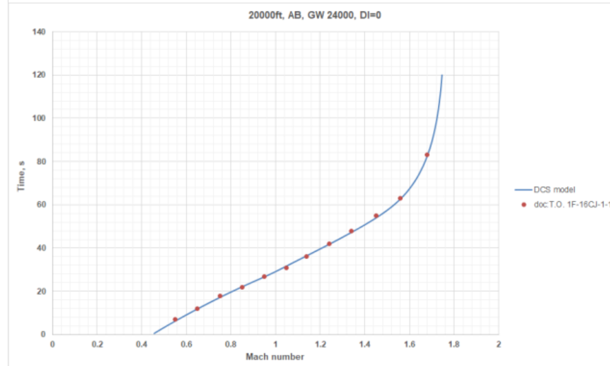


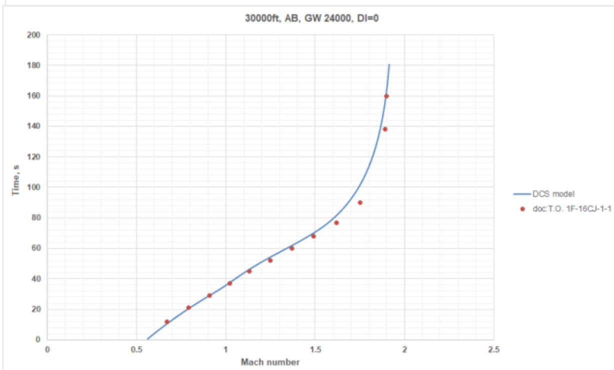


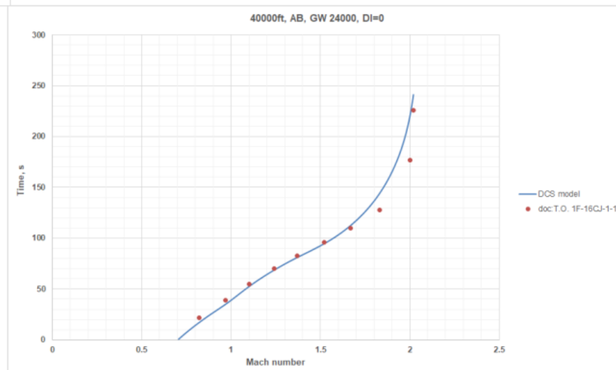





10000ft, AB, GW 24000, DI=0
Time, s
Mach number
DCS model
doc:T.O. 1F-16CJ-1-1


20000ft, AB, GW 24000, DI=0
Time, s
Mach number
DCS model
doc:T.O. 1F-16CJ-1-1


30000ft, AB, GW 24000, DI=0
Time, s
Mach number
DCS model
doc:T.O. 1F-16CJ-1-1


40000ft, AB, GW 24000, DI=0
Time, s
Mach number
DCS model
doc:T.O. 1F-16CJ-1-1