Aircraft Performance, Myths and Methods
A Real-world Example with Illustrations

A CAVU customer, using EFB-Pro during a recent recurrent class, was given this example and asked to find the max takeoff weight:

MMTO, 20C, no wind, 30.32", use runway 33. Toluca Six Departure

He reported to us that:

EFB-Pro gave an answer of 35,177 lbs while the instructor and FMS gave an answer of 39,100 lbs (per the worksheet below). The documents included here are actual copies from the instructor showing his hand drawn entries and notations on the charts.

Keep in mind, that even though this example utilizes a Challenger 605, it is <u>applicable to every Part 25 turbine aircraft</u>. This instructor's approach is by no means unique to this one instructor or this particular center. We have seen this methodology utilized ubiquitously throughout the industry.

Maximum Allowable Takeoff Weight Worksheet

- Two engine flight planning and performance

DEPARTURE AIRPORT TOLUCA, MEXICO (MMTO)					
Pressure Altitude	Temperature	Wind Component	Runway Length	Runway Slope	Climb Gradient Required
8,000 ft	20°C	0	13,780 ft	0%	200 ft/nm = 3.3%

DEPARTURE WEATHER	Engine Bleed Requirements		
0000kt 1SM BR OVC006 20/20 A3032	ACUs (On/Off)	Cowl A/I (On/Off)	Wing A/I (On/Off)
	OFF	OFF	OFF

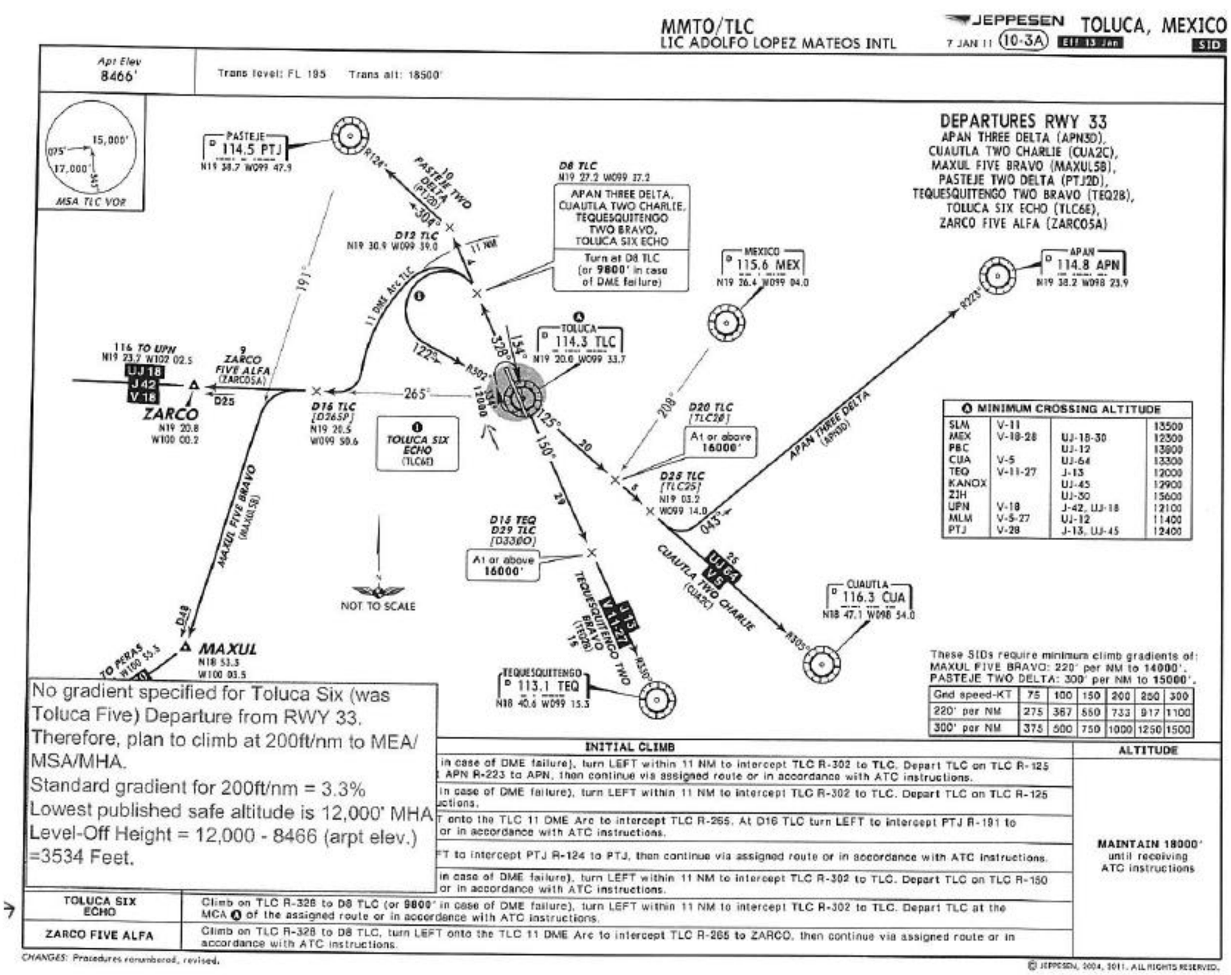
TAKE-OFF WEIGHT LIMITED BY:	Max Gross Wt (48,200)	Climb Req't (06-03-1)	Brake Energy (06-03-2)	Tire Limit Speed (06-03-3)	Take-Off Dist. (06-03-4)	Obstacle Clx (06-04-3)
APR Armed	48,200 lb	46,600 lb	45,400 lb	47,600 lb	47,500 lb	39,100 lb
APR Off						

TAKE-OFF DATA:	Take-Off Wt	Take-Off N1	Max Cont N1	V1	VR	V2	Take-Off Distance

How the Sim Center and FMS came up with 39,100 lbs

First, lets look at the departure procedure. The Toluca Six departure does not specify a climb requirement, therefore, and rightly so, 200ft/nm is assumed. 200ft/nm is a gross gradient of 3.3%. The lowest published safe altitude is 12,000 ft MSL.

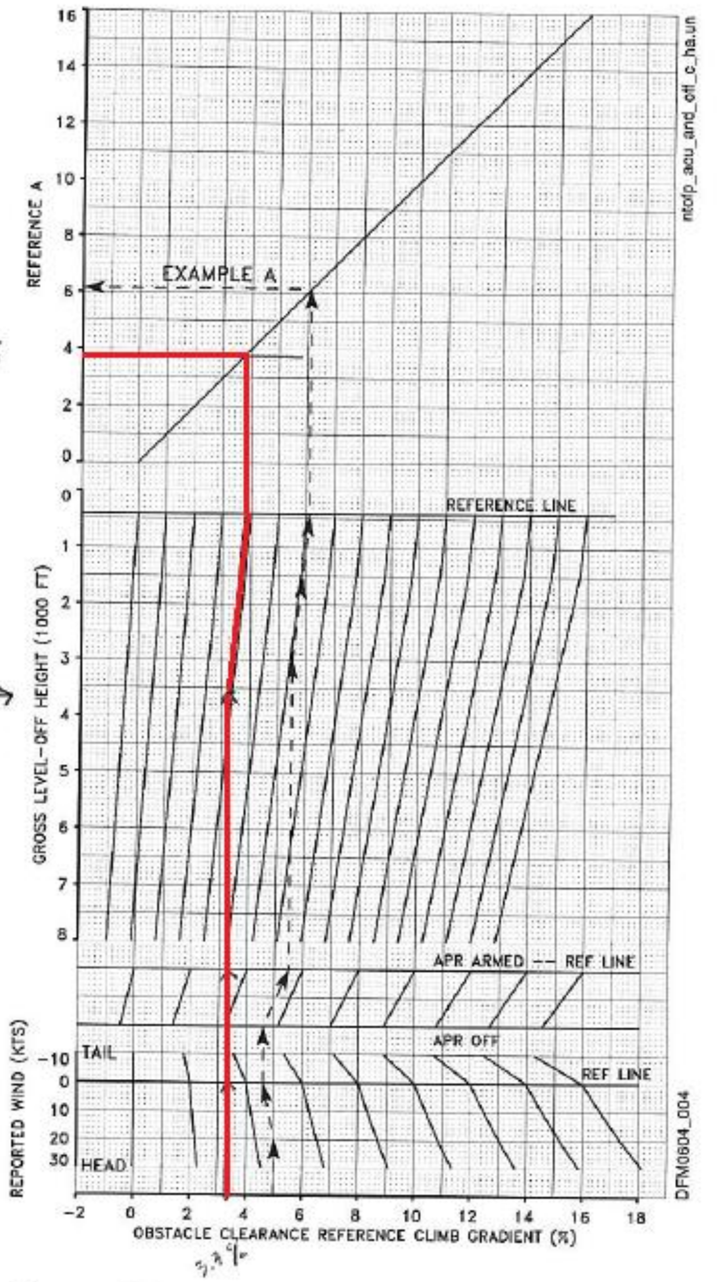
Since the field elevation is 8,466ft, the aircraft will need to climb 3,524 ft (the area below the obstacle indentification surface associated with a 200ft/nm gradient is assumed to be terrain).



The instructor then proceeded to chart 06-04-3 page 1 (Obstacle Clearance Reference Climb Gradient for Flaps 20, Ice Off). Entering the bottom of the chart at 3.3%, no adjustment was made for wind or APR (assumed armed). He then intercepted the Gross level-off height of 3,534ft and preceded up to the Reference A index of 3.9. (See chart below)

3. MAXIMUM TAKE-OFF WEIGHT LIMITED BY OBSTACLE CLEARANCE REQUIREMENTS (CONT'D)

REF A → 3.9

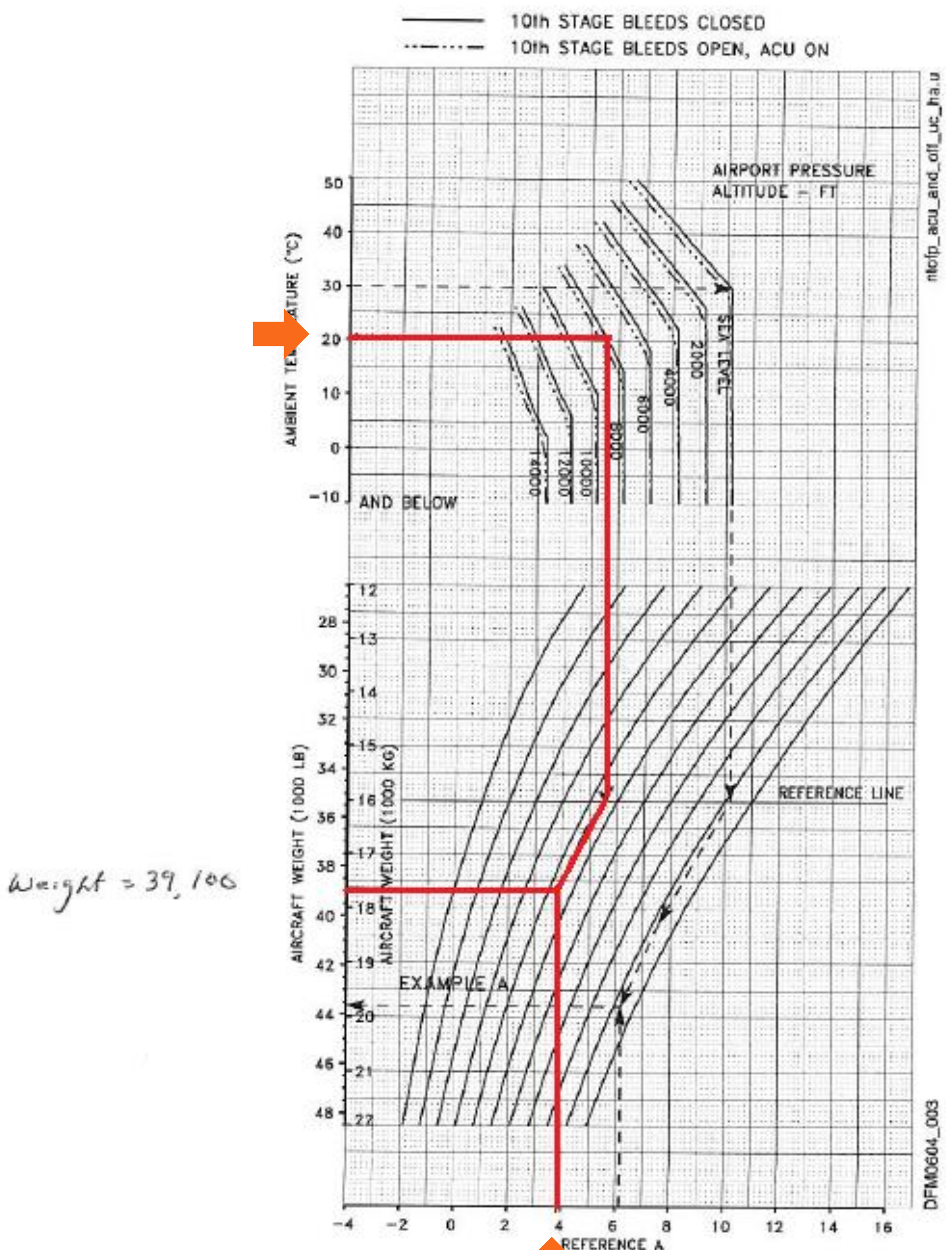


3534' → Level OFF Height

Obstacle Clearance Reference Climb Gradient, Flaps 20° – Anti-Icing Off (Page 2 of 2)
Figure 06–04–3

Moving to chart 06-04-3, page 2, the chart is again entered from the bottom this time using 3.9. The intersection of the line from the temperature/pressure altitude section (top section of chart) and the 3.9 from the bottom renders a result of 39,100lbs.

3. MAXIMUM TAKE-OFF WEIGHT LIMITED BY OBSTACLE CLEARANCE REQUIREMENTS (CONT'D)

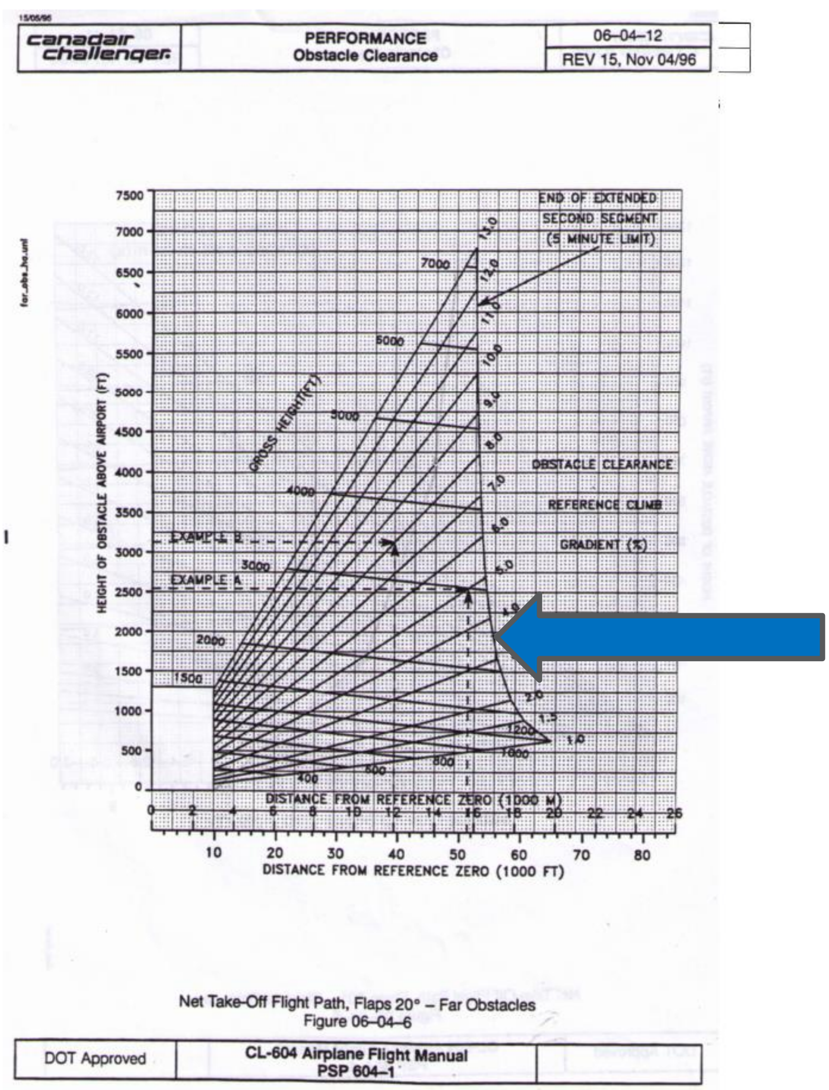


Obstacle Clearance Reference Climb Gradient, Flaps 20° – Anti-Icing Off (Page 1 of 2)
Figure 06–04–3

The Problem with this solution

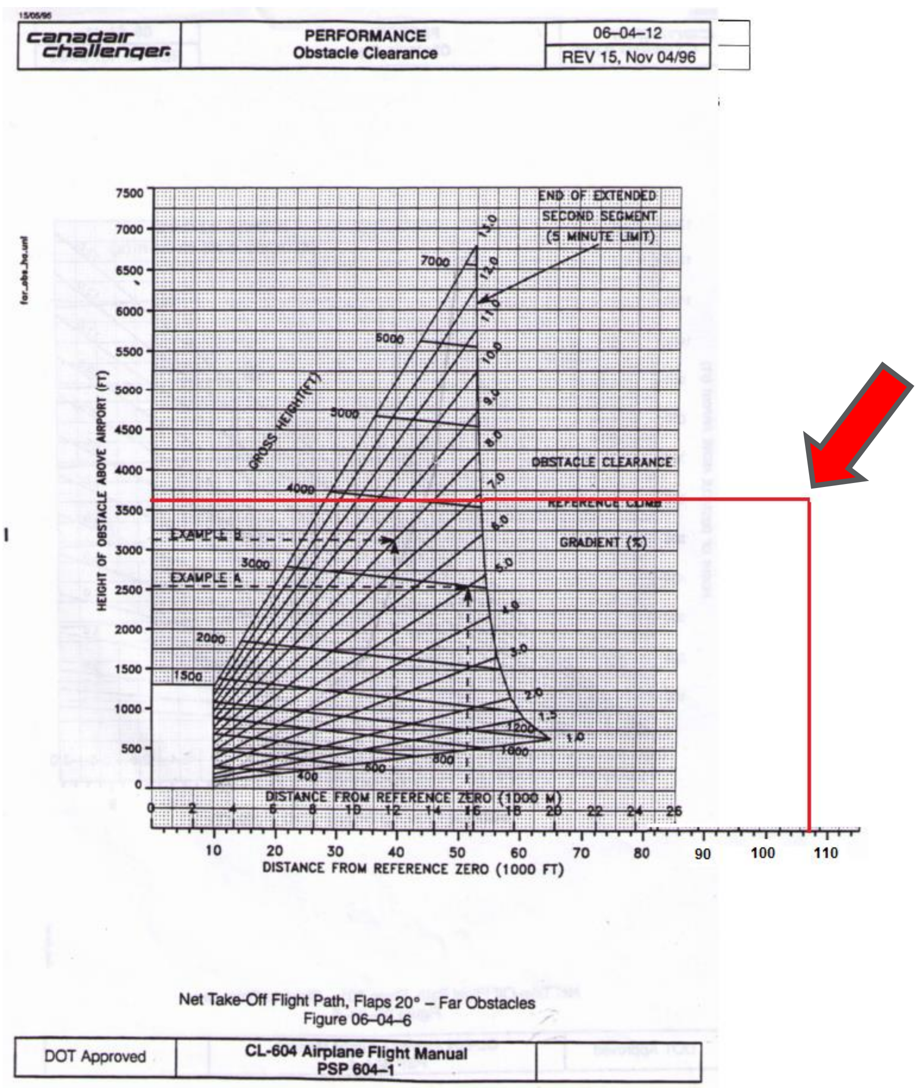
The flaw in this calculation begins with the assumption that the climb gradient upon which to base the maximum weight is in fact 3.3%. This assumption stems from using the wrong chart to start the calculation.

The correct chart to begin the calculation is 06-04-6 (Net Takeoff Flight Path, Flaps 20, Far Obstacles) below. This provides the reference climb gradient (note the same parameter name as the input to chart 06-04-3). Since climb performance degrades with altitude and time, the higher the obstacle and the further the obstacle is from the runway, the greater the degradation in climb performance. So if the calculated gradient is 3.3 but the obstacle is considerably down range, the initial gradient (or reference climb gradient in this example) might need to be 3.7%.



The second issue, that turning to this chart first would have revealed, is the engine time limit constraint. Note the right most vertical curved line of the chart (blue arrow above). This is the 5 minute limit line. In other words, an obstacle to the right of the line must be cleared significantly before reaching the obstacle. This is the case in this example.

Remember that the minimum climb requirement is 200ft/nm and the altitude gain required is 3,534 ft (12000-8466). This is our limiting “obstacle”. If we climbed right at 200ft/nm, the aircraft would be 17.67 miles downrange at the point in time that it reached 3534 AGL (12000 MSL). If we plot that on chart 06-04-6 below we get the following result (note: 17.67 miles is 107363 ft.).



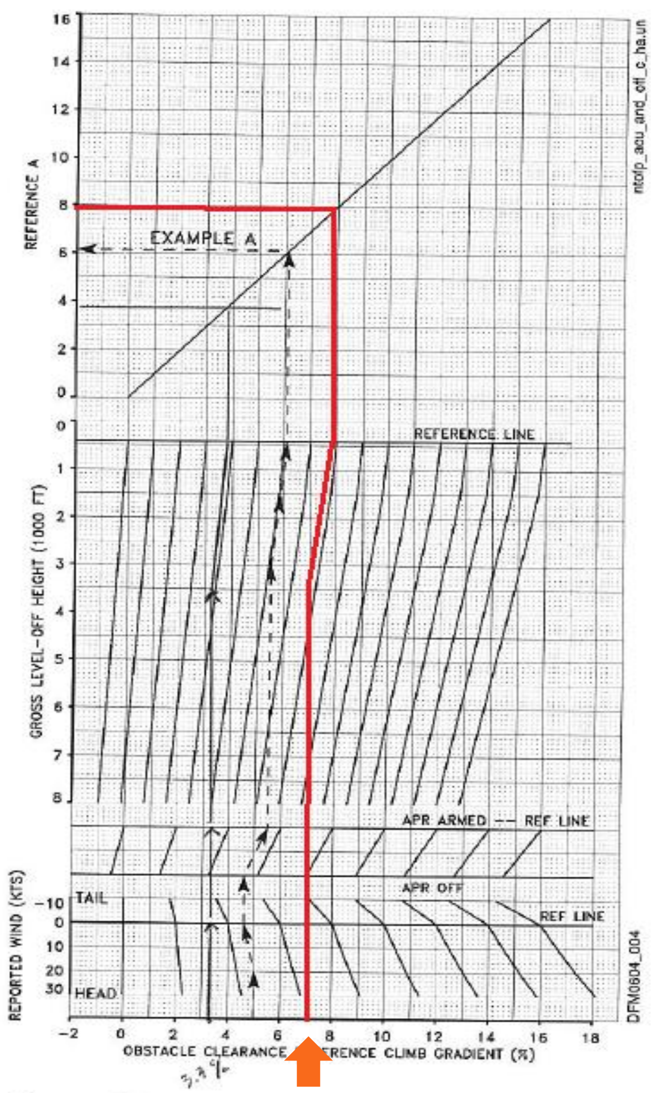
Note that the intersection of the red lines (red arrow above) is way to the right of the time limit line. The time it takes to reach the obstacle height at that climb rate far exceeds the 5 minute limit. This is <u>not</u> a viable option.

The first viable option available to us is to clear the “obstacle” within the 5 minute limit, then pull the power back to Max Continuous Power and “coast” over the top of the obstacle. This would require us to climb at a much steeper rate and the value of that climb gradient is found by moving back along the horizontal red line above until it falls within (to the left of) the time limit line. For simplicity, I’ll say that value is 7%.

Entering Chart 06-04-3 (below) at 7% and moving on to page 2, the maximum weight (for this option) is obtained.

BOMBARDIER CHALLENGER 605	PERFORMANCE Obstacle Clearance	06–04–6 Oct 05/06

3. MAXIMUM TAKE-OFF WEIGHT LIMITED BY OBSTACLE CLEARANCE REQUIREMENTS (CONT'D)

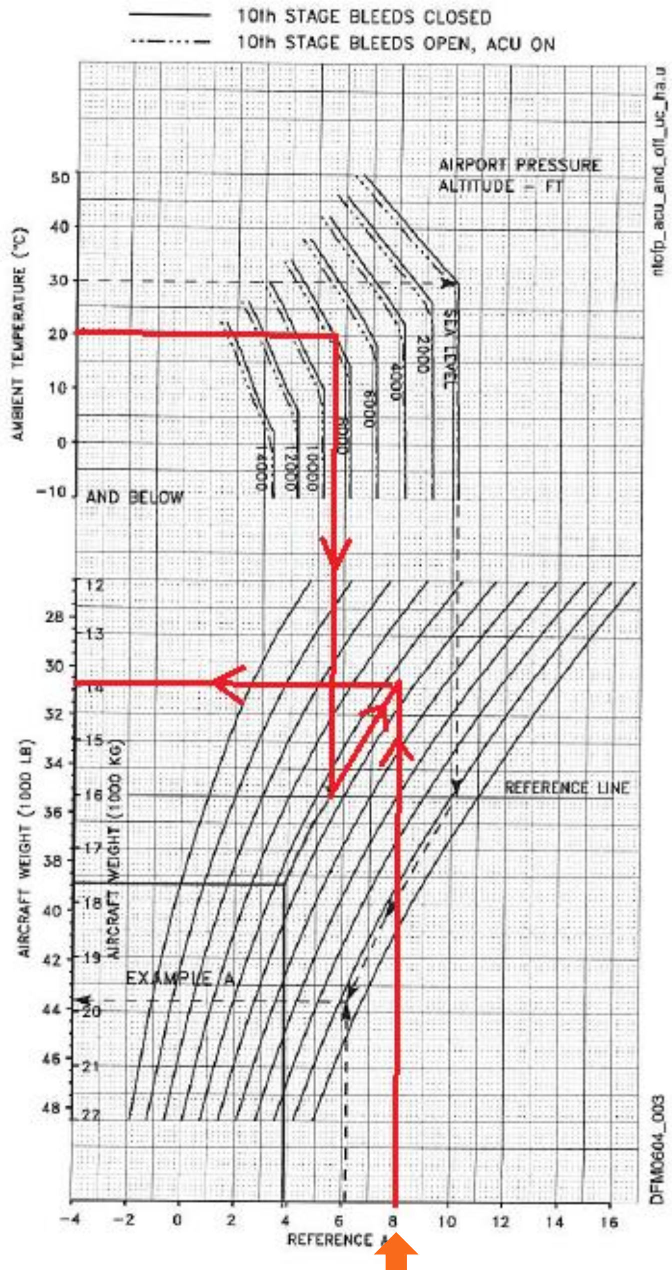


Obstacle Clearance Reference Climb Gradient, Flaps 20° – Anti-Icing Off (Page 2 of 2)
Figure 06–04–3

	CL–605 Airplane Flight Manual PSP 605–1	

PAGE PRINTED ON 22Jan2015 - UNCONTROLLED COPY

3. **MAXIMUM TAKE-OFF WEIGHT LIMITED BY OBSTACLE CLEARANCE REQUIREMENTS (CONT'D)**



Obstacle Clearance Reference Climb Gradient, Flaps 20° – Anti-Icing Off (Page 1 of 2)
Figure 06–04–3

The result of this option is a maximum weight of 30,750lbs. Ouch. That's 8350 lbs lower. Thankfully, there's a third option.

This option however, if done by hand, would take the average person 2 hours to calculate, but fortunately, EFB-Pro does all the heavy lifting for you in seconds.

This third option requires a level-off below the 3,534ft obstacle, raise the flaps, accelerate to Vfto, pull the power back from Max Takeoff to Max Continuous Power and then continue climbing at Vfto or Venr (depending upon your aircraft type and altitude). The reason the calculation takes so long by hand is that the second segment climb height and distance downrange, the level-off height and distance transversed and the final segment height and distance must all be matched to a specific weight and fit above the minimum climb gradient (200ft/nm gross) as we assume terrain occupies the space below the net minimum climb gradient. The other complicating issue is that the acceleration distance increases exponentially with weight while the second segment and final segment increase more linearly. So trial and error is really the only option available to optimize the takeoff weight.

Here is the solution using EFB-Pro (See screenshots below)

Select the airport MMTO

Notice the weather imports. I selected runway 33.

The Departure airport screen

For this example, I removed the wind and changed the temperature from 22C to 20C. Note that the field length, elevation and slope (in this case zero) are automatically entered.

On the Obstacles screen

I entered 200ft/nm and 12000ft.

There were no close-in obstacles and since the climb gradient ws 200ft/nm it didn't matter if I selected ICAO of TERPS. There was also no turn crossing height in the departure procedure.

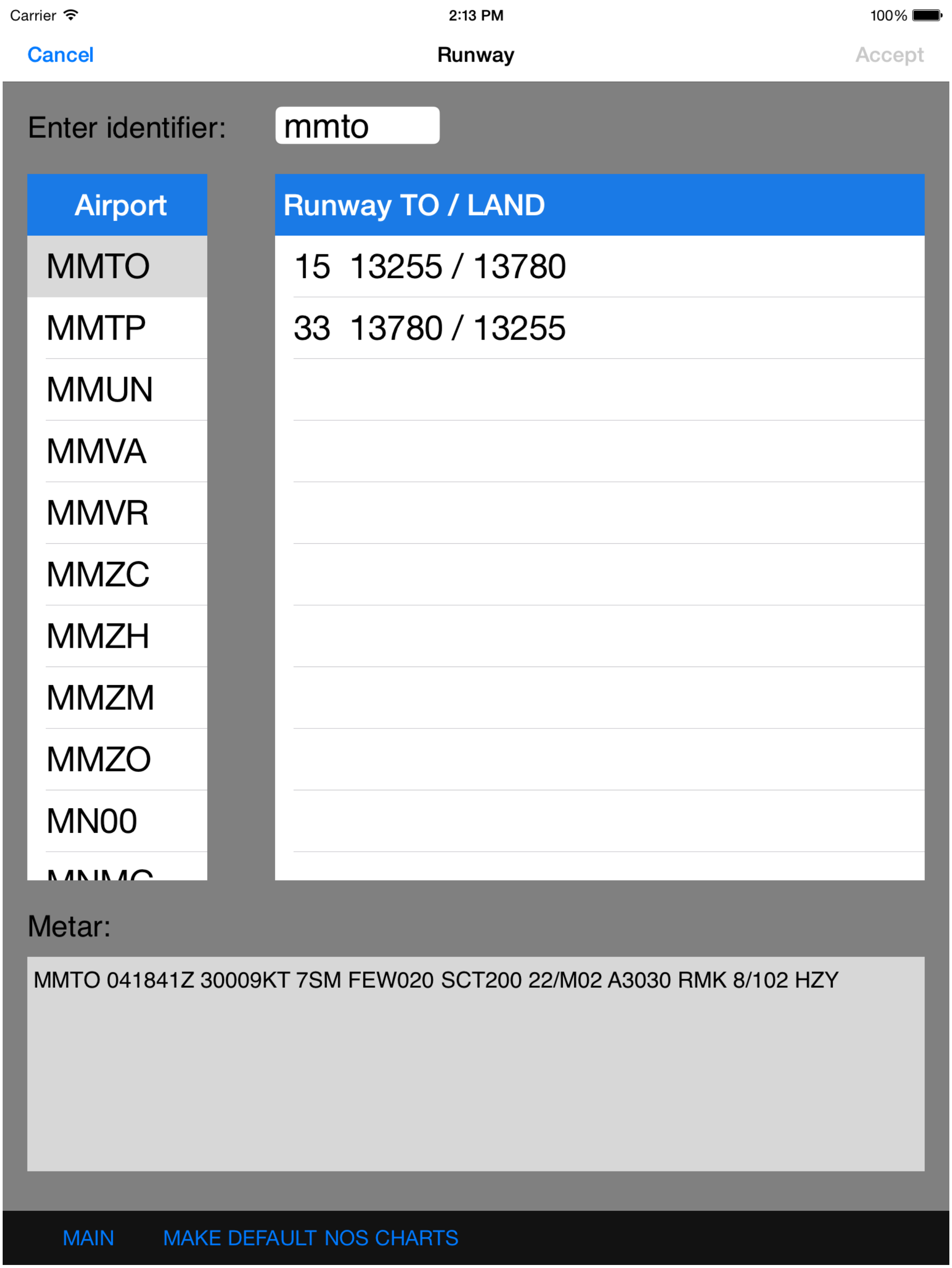
On the Settings screen

I toggled APR ARMED, %MAC came from the W&B

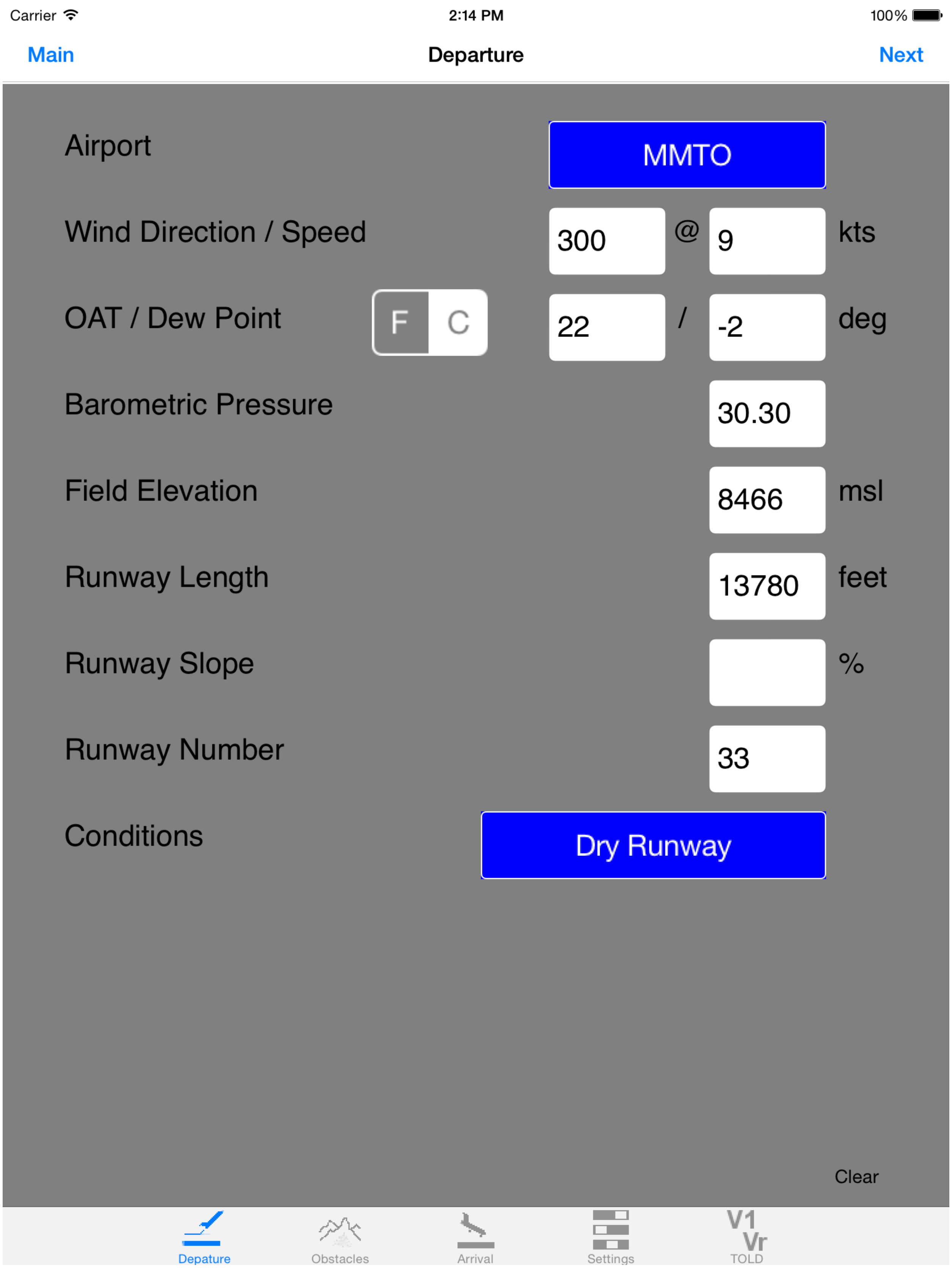
Result screen

Look below the last screenshot for an explanation of the results.

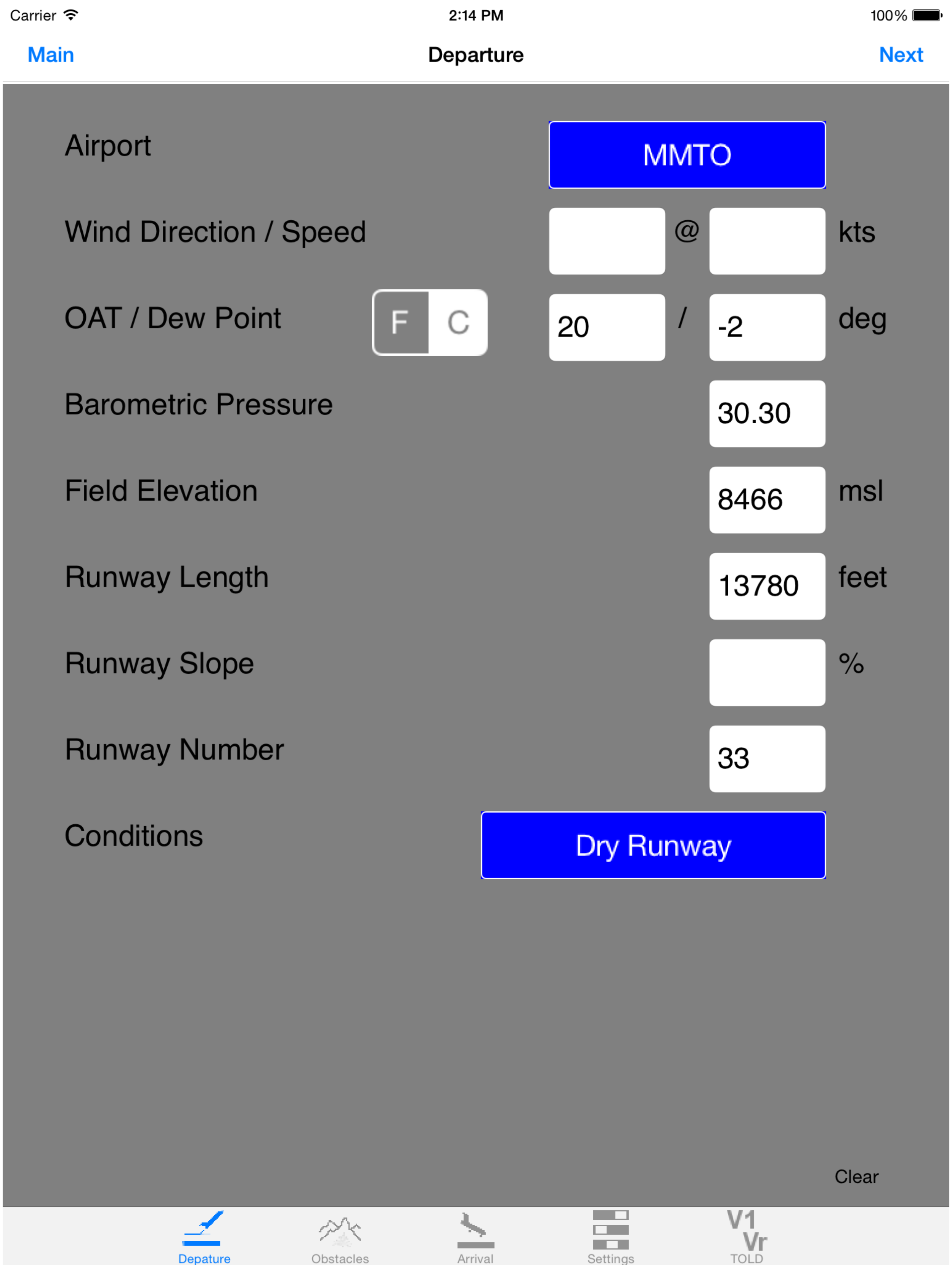
Airport Selection Screen



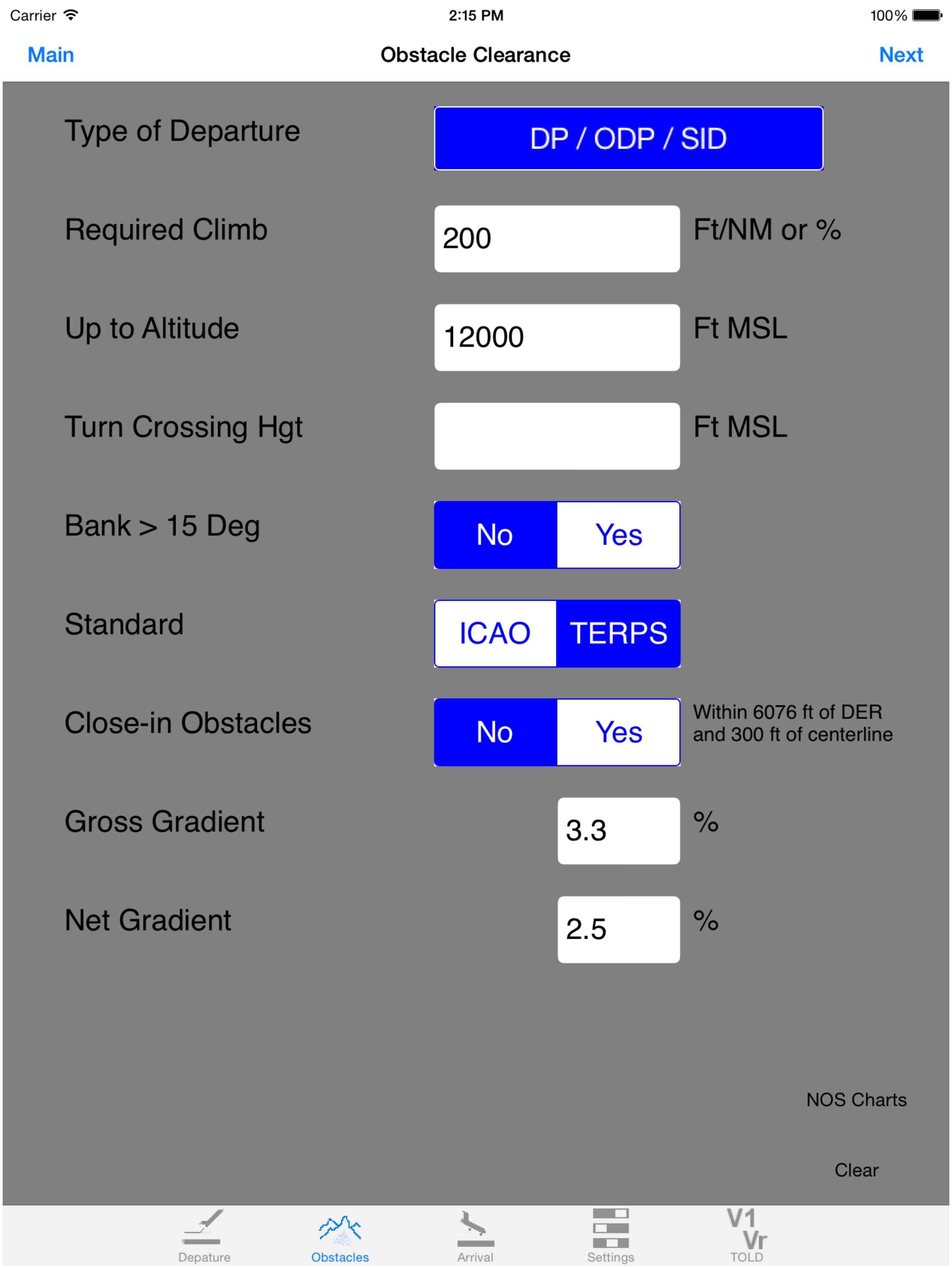
Unadjusted Departure Airport Field Conditions Screen



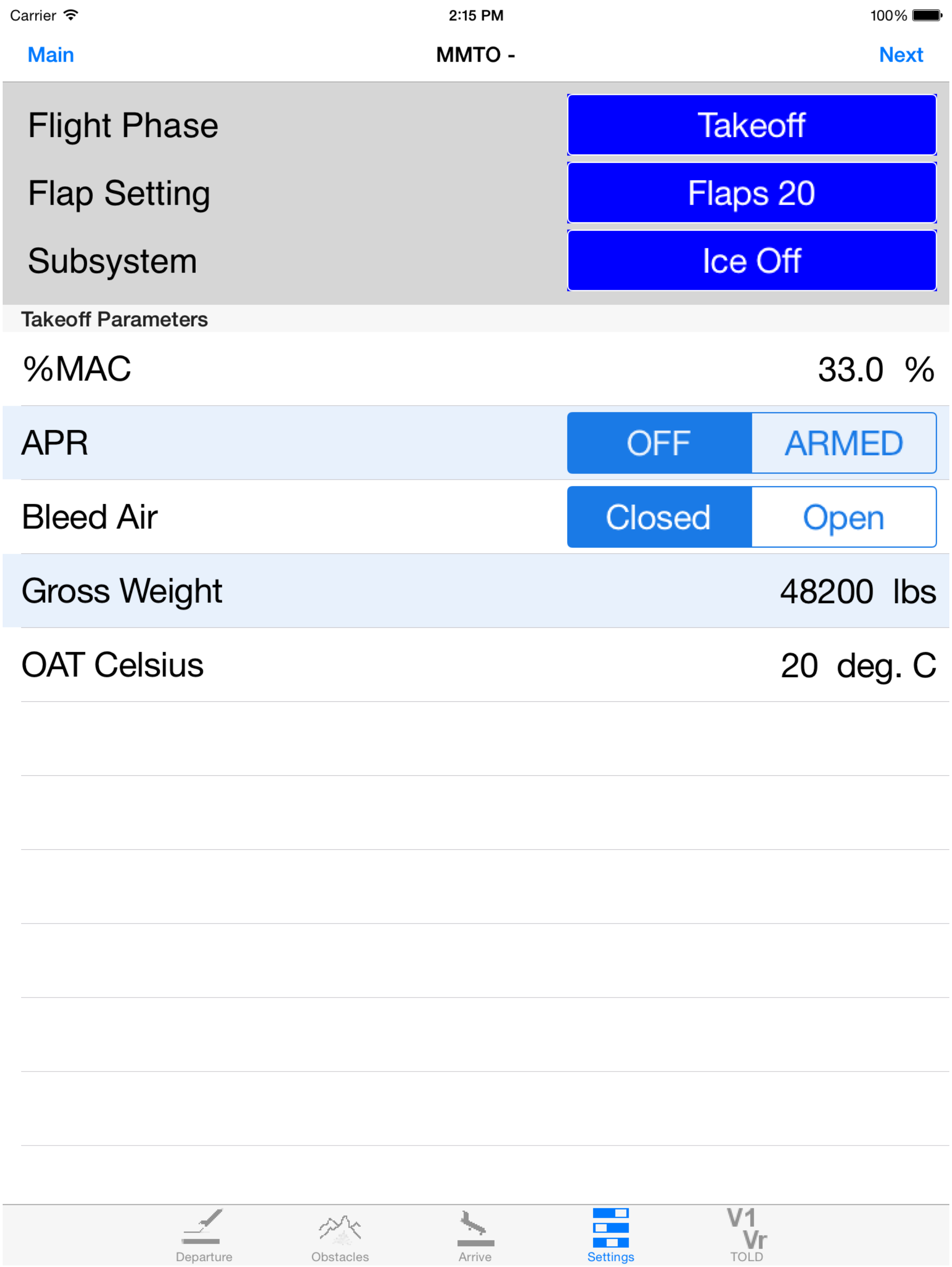
Manually Adjusted Field Conditions Screen



Obstacle Clearance Screen



Settings Screen



Results Screen (TOLD Card)

Carrier 2:20 PM 100%

Main | Takeoff - Flaps 20 - MMTO | Email TOLD Card

T/O N1 Zero Bleed	93.7 %
T/O N1 Bleeds Open	92.9 %
Trim Setting	3.8 %
Max Cont N1	95.1 %
Max Wgt,Climb	46708 Lbs
Max Wgt,Brake	45309 Lbs
Max Wgt,Tire	47474 Lbs
T/O Distance	10837 ft
Max Wgt Field	47201 lbs
Max Wgt 2nd Segment	35024 lbs
T/O Attitude	10.0 deg
Level Off	10819 msl
Vmcg	102 kts
V1	121 kts
Vr	127 kts
V2	134 kts
Vfto	161 kts
Venr climb	159 kts

Departure Obstacles Arrive Settings V1 Vr TOLD

Results Explanation

Note that there are Max Climb and Brake restrictions (blue is limiting but not the most restrictive, red is most restrictive) just as in the worksheet above. We used the actual field elevation so the numbers are slightly different than the worksheet above which rounds the value.

The 2nd segment restriction is 35,024 lbs (slightly different from the original answer from the customer due to a lower barometric pressure setting which came from the actual reported weather).

This solution requires a level-off, with max takeoff power, at 10,819 MSL. This number has been adjusted for temperature and pressure ("no high to low, look out below" concerns). If a turn crossing height had been required that too would have been converted and displayed.

Retract the flaps, accelerate to 161kts, reduce power to MCT (95.1%) and continue climbing.

Obviously, you will need to rerun the calculation once the actual takeoff weight is settled upon at which point all the values will be in black.

Concluding Comments

I hope this review will demonstrate that the FMS does not attempt to calculate a full four-segment Net Takeoff Flight Path profile; nor did this one take into account the impossibility of clearing the obstacle 17 miles downrange within the allotted time limit. This is typical of every FMS I have seen.

Secondly, it is clear that the use of abbreviated methods or reliance on tab data can render very erroneous results. This class was taught to takeoff 4,000 lbs heavier than what the AFM states.

Thirdly, there appears to be a trend toward teaching "FMS performance" at the expense of a more grounded and foundational understanding of AFM performance. I hope that it self-evident, that a thorough understanding of aircraft performance as depicted and explained within the AFM is vital.